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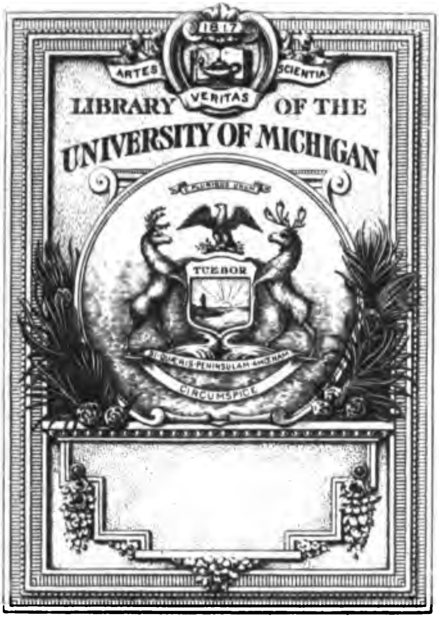

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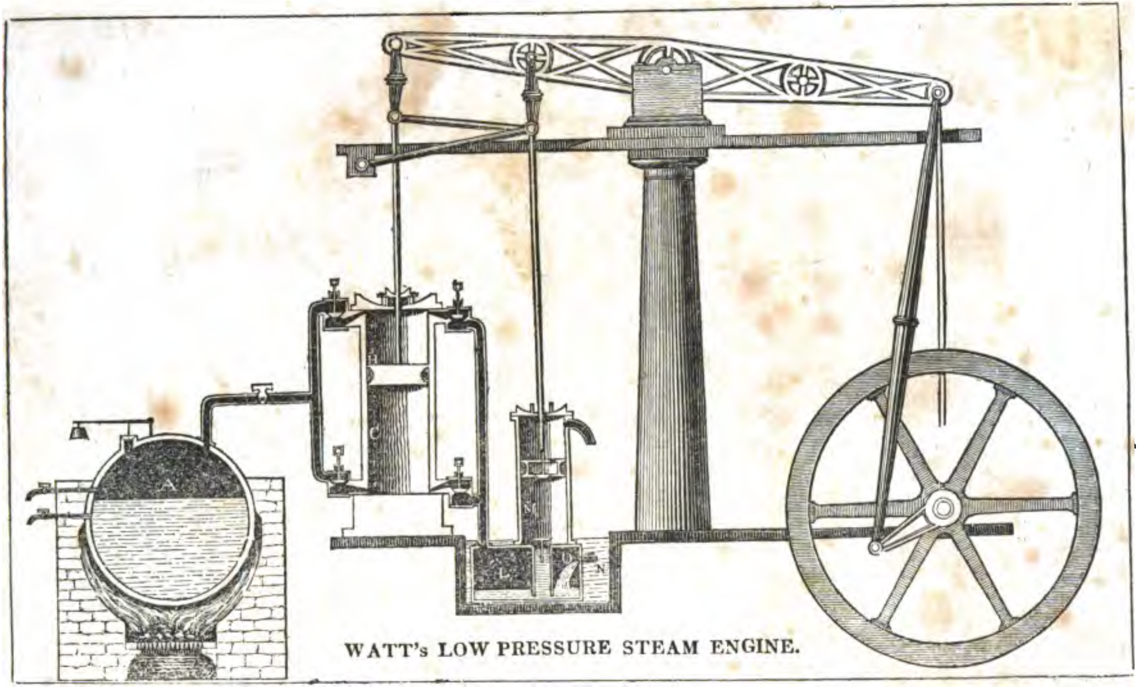

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PREFACE.

The **Conversations on Chemistry**, written by Mrs Marcet, have acquired and sustained a deservedly high reputation, and have undoubtedly, contributed more than any other work to promote the study of chemistry as a popular branch of education. The writer of the following pages is not so sanguine as to hope that his labours will obtain for him so rich a reward, although, in executing the task which he has undertaken, his principal motive has been to facilitate the acquisition of knowledge in a branch of science to which he has paid much attention, and of which he has for many years been a zealous, and, he believes, a successful teacher.

Some time since, he edited a revised edition of the **Conversations on Natural Philosophy**, by the same author, and was engaged to perform a similar task with those on chemistry. After passing over a few pages with this design, he found that it would be more difficult to adapt the work to the present state of the science than to remodel it altogether. Upon a careful comparison of the two works, it will be found, therefore, that although a few pages of the original have been retained, with but slight alterations, the conversations are, in general, entirely new.

About twenty-five years have elapsed since the **Conversations on Chemistry** were first published; and in a department of science so progressive as that to which they relate, advances have been made during this interval which have affected it in nearly all its branches. Many judicious alterations, it is true, have been made in the successive editions of the work; but still the original platform has remained unchanged, although some of the supports upon which it rested have given way with the lapse of time.

The **Conversations on Chemistry** were undoubtedly intended as a companion for the parlour, and they were admirably adapted to the end proposed. The many excellencies of the work, however, have caused it to be extensively adopted for the use of classes in schools; but its employment in this way has been accompanied by many difficulties, as those colloquial digressions which gave variety and interest to it in the family circle, were altogether unsuited to the business of the school room. Whilst, in the following work, an attempt has been made to imitate the style, and to preserve some of those interesting traits which rendered the original work so acceptable to every person of taste, the object in view has imposed some sacrifice in these particulars. A much greater number of facts have been embraced within the same space, and it is hoped that the sacrifice which was unavoidable under the particular views of the writer, will not be unattended by those advantages which it has been his object to attain.

It may be thought by some persons that several of the conversations contain matter too abstruse for an elementary work. After much consideration upon the subject, the author has arrived at a different conclusion. Although a judicious teacher may think it wise, in the first instance, to omit some of the conversations, either in whole or in part, the matter contained in them will not vitiate the other portions of the work, and may be advantageously included in a re-examination of the subject.

The numbers which refer to the questions will be found of great advantage in directing the pupil to the subject matter of inquiry. The list of experiments has been confined to those which are used as illustrations in the work; and where it has been thought necessary, some additional instructions have been given for the performance of them. The Glossary has been introduced for the purpose of explaining a few terms, and introducing certain facts, which could be most conveniently placed there. It was thought altogether unnecessary to extend it further; as, in most instances, the general index will furnish the means of obtaining a more satisfactory explanation of the language of chemistry, than could be afforded by a mere glossary.

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Vegetable Principles of the Third Class. Sugar and its Manufacture. Molasses, Loaf-sugar, Sugar-candy, and Barley Sugar. Honey, Sugar of Grapes, and Manna. Gum or Mucilage. Distinction between Gums and Resins. Fecula or Starch, Arrow Root, Tapioca, and Sago. Fecula converted into Sugar by Sulphuric Acid, by Fermentation, and by Germination. Malting. Gluten. Tannin. Lignin or Woody Fibre. Colouring Matter, Lakes, and Dyeing. Adjective and Substantive Colours and Mordants. Fermentation. Saccharine. Vinous. Use of Yeast. Nature and Combustion of Alcohol. Ethers. Sulphuric Ether. Aphlogistic Lamp. Acetous Fermentation, Acetic Acid, Vinegar, and Pyroligneous Acid. Products of the Putrefactive Fermentation. 290

CONVERSATION XXX.

ON ANIMAL CHEMISTRY.

The Constituent Principles of Animal Matter found in Vegetables. Their Proximate Principles more complex. Fibrin. Albumen.

Fining of Wine, Coffee, &c. Gelatin, Glue, and Ichthyocolla. Osmazome. Process of Tanning. Acids existing in the Animal System. Animal Oils and Fats. Stearine and Elaine. Margaric and Oleic Acids. Glycerine. Adipocere. Formation of Oils from their Constituents. Milk, Cream, Caseous Matter or Curd, Whey, and Rennet. 299

CONVERSATION XXXI.

ON DIGESTION, SECRETION, ANIMAL HEAT, &c.

Formation of Chyme and Chyle. Bile, its secretion and use. The Gastric Juice. Its remarkable solvent power. Circulation of the Blood. Arterial and Venous Blood. Change produced in the Blood by Respiration. Priestley's Experiments on the Effects of Oxygen on Venous Blood. Permeability of Membranes. Carbonic Acid exhaled from the Lungs. Animal Heat influenced by Respiration. Conclusion. 306

Glossary of Chemical Terms.

Conversations on Chemistry.

CONVERSATION I.

ON THE GENERAL PRINCIPLES OF CHEMISTRY.

Intimate connexion of Chemistry and Mechanical Philosophy. Chemistry as a Science and as an Art. Ancient and Modern Chemistry. Difference between Mechanical and Chemical Action. Definition of Chemistry. Simple and Compound Bodies. Analysis and Synthesis. Chemical Attraction. Affinity, or Elective Attraction.

Mrs B. As you have already acquired some knowledge of the elementary principles of Natural Philosophy, I now propose to direct your attention to a kindred branch of science, the study of which will equally reward you for your exertions—I mean *Chemistry*. You will find this science to be so intimately connected with Natural Philosophy, as to open to you new views upon that subject, and to convince you that an acquaintance with the one must be very incomplete without a corresponding familiarity with the other(1). Natural Philosophy explains the general laws by which bodies are governed, in their sensible motions; but the ideas which you form of the bodies themselves must be very defective, if you remain totally ignorant of the nature of the substances of which they are composed,

Caroline. Although the study of chemistry has become very fashionable, and I have no doubt is sufficiently amusing, yet to confess the truth, Mrs B. after seeing nature exhibited on a magnificent scale in the revolutions of those immense masses, the planetary orbs; after examining the laws by which they operate upon each other, notwithstanding the millions of miles by which they are separated, I cannot help turning to the petty details of the distiller, the compounder of medicines, and the manufacturer of perfumes, with a feeling of their comparative littleness, and a conviction that they are not calculated to excite in the mind those sentiments of grandeur and sublimity, which result from the contemplation of the mechanism of the universe.

Mrs B. You appear to me, my dear Caroline, to be somewhat too imaginative in your views, and I think you will by and bye confess that the little value which you are at present disposed to place upon chemistry results entirely from the limited idea which you entertain of its object. You also seem to confound together two things which differ essentially, chemistry as a science, and chemistry as an art(2). The latter is frequently pursued by persons unacquainted with its principles; whilst as a science, it has commanded the attention, and rewarded the inquiries of men of the most

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1. With what other department of science is chemistry most intimately connected, and what advantage will result from an acquaintance with it?
2. Chemistry may be divided into two departments, what are they?

exalted talents(3). Nature has the universe for her laboratory, in which she is continually employed in chemical operations, producing effects as interesting, as wonderful, and equally necessary with those which belong to Natural Philosophy(4).

The study of the works of nature is divided into three grand branches—*Natural History*, *Natural* or *Mechanical Philosophy*, and *Chemistry*(5). The first teaches us to distinguish bodies from each other by their external forms and characters(6); the second inquires into the effects produced by bodies upon each other, from their mechanical action only, such as their gravity, weight, and motion(7);—the third, *Chemistry*, examines into the intimate nature of bodies, that is, into the nature of the materials of which all bodies are composed(8); and I have no doubt you will soon agree with me in thinking it the most interesting of the three. You may easily conceive, therefore, that without entering into the minute details of practical chemistry, you may obtain such a knowledge of this science as will not only excite a new interest in the common occurrences of life, but will also enlarge the sphere of your ideas, and render the contemplation of nature a source of delightful instruction.

Caroline. I confess that I am already convicted of having been too precipitate in the judgment, or rather in the notion, which I had formed of chemistry; for although I knew that it was not entirely confined to the art of preparing drugs and other compounds, yet I considered this as its principal object.

Mrs B. There is a branch of practical chemistry called *Pharmacy*, which relates exclusively to the preparing of medicine, and it is undoubtedly an art of great importance to professional men, and indeed to the world at large(9); but in studying chemistry as a science, we have no more to do with this as an art, than we have with the method of grinding glasses, when acquiring a knowledge of optics.

Emily. I have frequently read of the alchemists, and their endeavours to discover the philosopher's stone, and the art of making gold; pray what is the difference between these men and the modern chemists?

Mrs B. The alchemists were a set of misguided philosophers, who assumed this name to distinguish themselves and their pursuits from the common chemists, whose studies were then confined to the knowledge of medicines(10).

Many of the alchemists were men of great genius, but their pursuits partook largely of the ignorance of the dark ages in which they lived, being generally intermingled with the exploded notions of magic, and astrology. Their whole proceedings were consequently involved in mystery and secrecy; but since that period chemistry has undergone so complete a revolution, that from an obscure and mysterious art, it has now become a regular and beautiful science, comprehending in the sphere of its inquiries the nature of every substance found in the material world(11).

The alchemists imagined that all metals contained one common principle, and that the difference between them arose from the combination of this principle with certain impurities: it was only necessary, therefore, to remove e, in order to the conversion of either of them into gold, the making

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remarked of the persons who pursue them respectively?
said of the *laboratory* of nature?
the three grand divisions of the study of the works of nature?
the first teach?
nd? 8. What the third? 9. What is *Pharmacy?*—
alchemists, and what their pursuits?
s chemistry undergone since their day?

of which precious metal was the great object of their researches. The *philosopher's stone*, which they hoped to form or to discover, was to be the substance with which they were to accomplish this grand design(12).

Although these visionary schemes entirely failed, yet the labours of the alchemist were not performed in vain. Scarcely any known substance escaped their investigations, and years were sometimes devoted to a single experiment. The result of this industry was, the discovery of the greater number of the active preparations used by the physician, and numerous valuable compounds employed in the arts. They were thus the means of increasing, to a wonderful extent, the conveniences and luxuries of life(13).

Caroline. Do pray, madam, tell us more precisely in what manner the discoveries of the alchemists, and of the chemists, have proved so beneficial to society.

Mrs B. Patience, my child; you would not now be able to comprehend the nature of their discoveries, although they may hereafter be rendered quite easy and familiar to you. In order to this, however, we must pay a due regard to method, as without it you will not be able to make any progress in chemistry. I shall, in the first place, explain to you some of the chemical operations of nature; from these, the transition to those of art will become quite easy, and they, also, are sufficiently important to claim a large share of our attention.

Emily. Well, then, let us now set to work regularly; I am very anxious to begin, and shall be obliged by your first giving us a more distinct idea of the difference between natural philosophy and chemistry.

Mrs B. Natural philosophy, in its most comprehensive sense, would embrace both these departments of science, and they were in fact both included under this term, until the progress of chemistry gave to it a just claim to rank as a distinct department(14). The name *mechanical philosophy* is now generally substituted for natural philosophy, and ought to be so, uniformly; as all the changes that take place in bodies which are not *chemical* are *mechanical*, whilst they are both perfectly *natural*(15).

We perpetually see many of the substances in nature changing their properties, appearing to be transmuted, or converted into others which bear little or no resemblance, either in form or substance, to the materials from which they were produced(16). Thus iron, when exposed to air and moisture, becomes converted into a brown earthy substance, which we call rust(17); our candles also, and other combustibles, when burned, appear to be annihilated, or put out of existence(18), an event, the impossibility of which you have already learned in your natural philosophy.

Chemistry investigates the nature and causes of those changes which take place in the intimate nature, or composition of bodies, whether these changes be slowly or rapidly, naturally or artificially produced(19).

A substance may be broken into pieces, it may be reduced into the finest powder, or it may be removed from one place to another, by *mechanical* force, without any other change in it than that of size, or place; but whenever a body is so acted upon as to have its *nature* altered, the action is *che-*

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12. What idea did they entertain respecting the metals?
13. What advantage has the world derived from their pursuits?
14. What might be comprehended in the term natural philosophy?
15. What is natural philosophy now called, and what renders it proper?
16. What changes do we perpetually witness?
17. What is the first example given?
18. What the second?
19 What are the objects of chemical investigation?

mical(20). You will find, therefore, Caroline, that chemistry is no narrow or confined science, but that it comprehends every thing material within our sphere of observation.

Caroline. It must indeed be inexhaustible, and I am now at a loss to conceive how any proficiency can be made in a science whose objects are so numerous.

Mrs B. If every individual substance were formed of different materials, the study of chemistry would, indeed, be endless; but you must observe that the various bodies in nature are composed of certain simple substances, or elementary principles, which are not very numerous(21).

Caroline. Yes; I know that all bodies are composed of fire, air, earth and water; I learnt that many years ago(22).

Mrs B. But you must now endeavour to forget it. I have already informed you how great a change chemistry has undergone since it has become a regular science. Within these forty years especially, it has experienced an entire revolution, and it is now proved that neither fire, air, earth, or water, can be called elementary bodies. An elementary body is one that has never been decomposed, that is to say, separated into other substances(23). Air, earth, and water, are all of them susceptible of decomposition, and the same may probably be asserted of fire(24).

Emily. I thought that decomposing a body was dividing it into its minutest parts. And if so, I do not understand why an elementary substance is not capable of being decomposed, as well as any other.

Mrs B. You have misconceived the idea of *decomposition;* it is very different from mere *division.* The latter simply reduces a body into parts, but the former separates it into the various ingredients, or materials, of which it is composed(25). If we were to take a loaf of bread, and separate the several ingredients of which it is made, the flour, the yeast, the salt, and the water, it would be very different from cutting or crumbling the loaf into pieces(26).

Emily. I understand you now very well. To decompose a body is to separate from each other the various simple or elementary substances of which it consists.

Caroline. But flour, water, and the other materials of bread, according to your definition, are not elementary substances.

Mrs B. No, my dear; this separation of the ingredients of bread would be only a partial decomposition; but it may serve to give you a familiar idea of what is intended.

The elementary substances of which a body is composed are called the *constituent* parts of that body; in decomposing it, therefore, we separate its constituent parts(27). If, on the contrary, we divide a body by chopping it to pieces, or even by grinding or reducing it to the finest powder, each of these small particles will still consist of a portion of the several constituent parts of the whole body: these are called the *integrant* parts(28); do you understand the difference?

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20. How would you discover whether a body had been acted upon mechanically or chemically?

21. Are all substances which differ formed of different materials?

22. Of what elements does Caroline suppose all bodies to be formed?

23. What is meant by an elementary substance?

24. What is said respecting what were once called the four elements?

25. What is the difference between mere division and decomposition?

26. Give the example.

27. What is meant by the *constituent* parts of a body?

28. What by integrant parts?

Emily. Yes. I think perfectly. We *decompose* a body into its *constituent* parts, and *divide* it into its *integrant* parts.

Mrs B. Exactly so. If therefore a body consists of only one kind of substance, though it may be divided into its integrant parts, it is not possible to decompose it. Such bodies are therefore called *simple* or *elementary*, as they are the elements of which all other bodies are composed. *Compound bodies* are such as consist of more than one of these elementary principles(29).

Caroline. Pray what is the difference between *decomposing* and *analysing* a body? so far as I understand the terms, they appear to be perfectly synonymous.

Mrs B. But they are not so, my dear; for although you cannot *analyze* a compound body without *decomposing* it, you may *decompose* without *analyzing* it. The wood and coal which we burn in our fires are compound bodies, and are decomposed in their combustion; but they are not analyzed. When we analyze a body, we do not allow any part of it to escape, but collect all the different substances into which it can be resolved by decomposition, whether they be solids, liquids, or airs(30).

The object of analysis is to ascertain of what simple, or elementary substances a body is composed, and the relative quantity of each, which enters into its composition(31).

There is necessarily one class of bodies which we cannot decompose; they are what we have denominated *simple;* and when any substance resists every attempt to decompose it, we then place it in this class of bodies(32).

Emily. But I should think that, after all, the chemist may be mistaken, and give us a list of simple substances, which those who come after him may find to be compound.

Mrs B. I am pleased with your remark, as it leads me to tell you that it is not pretended that all the bodies which are classed as simple are absolutely so. Some which were formerly so classed, are now known to be compounds; it is probable, therefore, that as the methods and instruments of examination are improved, the class of simple substances may be either reduced or increased in number(33).

Caroline. I remember seeing in a work upon chemistry, which I took up some time ago, that there were *three* modes by which a judgment was formed respecting the compound nature of a substance; one of them, analysis, I think I perfectly understand, and should like to know something about the other two; these I think were *synthesis* and *analogy*(34).

Mrs B. Synthesis is the very reverse of analysis, and means *the re-forming of a compound body, by causing the simples of which it was compounded to unite together, and to reproduce the same substance, identical in all its properties*(35). When we can both decompose and recompose a body, or in other words, give an analytical and synthetical proof of its composition, the evidence is viewed as complete(36).

Caroline. Although I do not pretend yet to know any thing of chemistry,

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29. What are those bodies which cannot be decomposed, and what are compounds?
30. State the difference between mere decomposition and analysis.
31. How is analysis defined?
32. What circumstance induces us to term bodies simple?
33. Does our placing a body in this class necessarily imply that it is so?
34. There are said to be three modes of judging of the compound nature of a body; what are they?
35. What is synthesis?
36. When do we view the evidence of the composition of a body complete?

I think that I can perceive the use which the chemist makes of analogy, as the word means resemblance or similarity. I suppose that when a substance which has not yet been decomposed, possesses a striking resemblance in some of its distinguishing properties to others which have been decomposed, it is then classed among compound bodies(37).

Mrs B. Your remark, Caroline, is both acute, and generally speaking, correct; the chemist, however, would not class an undecompounded body with those which had actually been decomposed. You must therefore consider the list of simples to be no other than a catalogue of undecompounded substances, the greater number of which are most probably elementary(38).

Emily. I should like first to learn the names of all the substances accounted simple, so that I may understand something about them when I meet with them again, as we proceed with the study of chemistry; I hope, however, that they are not very numerous.

Mrs B. I think that it would be unwise for you to commence by learning these names, as there are about fifty of them(39). A moment's reflection must convince you that in order to know them when you meet with them, you must first become in some measure acquainted with them. I shall, therefore, introduce them to you, either individually or in classes, as we examine their properties; you will thus the more readily become familiar with them.

Emily. I own my folly, and will in future endeavour to think more correctly before I tell my thoughts. I should be sadly at a loss to pick out fifty strangers by merely having a list of their names. But are the whole of these fifty substances new to us?

Mrs B. No my dear; about two-thirds of the whole number belong to one class, the metals(40), with several of which you are already familiar; others of them are not of very great importance. As I shall endeavour to guide you systematically, I think you will find that all the difficulty which you apprehend respecting the names, not of these simples only, but of the numerous compounds which they form, will entirely vanish.

Caroline. As in natural philosophy, the attractions of cohesion and of gravitation act a most important part, I suppose that *chemical attraction*, or *affinity*, which you formerly named to us, is equally influential in chemical operations(41).

Mrs B. You are perfectly correct Caroline, and although you are at present unacquainted with the nature of most of the simple substances, it will be necessary to anticipate our subject in some degree, and speak of them as though you knew them.

Chemical attraction, or the *attraction of composition*, consists in the peculiar tendency which bodies of a *different nature* have to unite with each other. It is by this force that all the compositions and decompositions are effected(42).

The attraction of cohesion exists only between particles of the *same* nature, whether simple or compound; thus it unites the particles of a piece of metal, which is a simple substance, and likewise the particles of a loaf of bread, which is a compound. The attraction of composition, on the contrary, unites and maintains in a state of combination, particles of a *dissimilar* nature. It is this power that forms each of the compound particles of which

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37. State the nature of the judgment by analogy.
38. How are we to consider the list of simples?
39. How many simple substances are known?
40. How many of them belong to the class of metals?
41. What species of attraction belongs to chemistry?
42. In what does chemical attraction consist?

bread consists; and it is by the attraction of cohesion that all these particles are connected into a single mass(43).

Emily. The attraction of cohesion, then, is the power which unites the *integrant* particles of a body; the attraction of composition that which combines the *constituent* particles. Is it not so(44)?

Mrs B. Precisely: and observe that the attraction of cohesion unites particles of a similar nature, without changing their original properties. The result of such a union, therefore, is a body of the same kind as the particles of which it is formed; whilst the attraction of composition, by combining particles of a dissimilar nature, produces compound bodies, quite different from any of their constituents. If, for instance, I pour on the piece of copper contained in this glass, some of this liquid, which is *sulphuric acid*, (oil of vitriol,) mixed with some *nitric acid*, (aqua fortis,) the copper will be dissolved in the acid, and this will take place in consequence of the strong chemical attraction which exists between the particles of these two substances. Observe the internal commotion of the liquid, and the coloured fumes which are escaping. The process going on is too complex for you now to understand; but every particle of the copper is uniting with a particle of the sulphuric acid, and when they are combined together, they will form a new body, totally different from either the copper or the acid(45). The acid has, in this case, to overcome, not only the resistance which the strong cohesion of the particles of copper opposes to their combination with it, but also the weight of the copper, which makes it sink to the bottom of the glass, and prevents the acid from having such free access to it as it would if the metal was suspended in the liquid(46).

Emily. The acid seems, however, to overcome both these obstacles without difficulty, and appears to be very rapidly dissolving the copper.

Mrs B. By this means it reduces the copper into more minute parts than could possibly be done by any mechanical power. But as the acid can act only on the surface of the metal, it will be some time before the union of these two bodies will be completed.

You may, however, already see how totally different this compound is from either of its ingredients. It is neither colourless, like the acid, nor hard, heavy, and ruddy, like the copper; and if you were to taste it, you would no longer perceive any of the sourness of the acid. It has at present the appearance of a blue liquid; but when the union is completed, and the water with which the acid is diluted is evaporated, the compound will assume the form of regular crystals of a fine blue colour, and perfectly transparent(47). Of these I can show you a specimen, as I have procured some for that purpose. These crystals are *sulphate of copper*, commonly called blue vitriol, one of the metallic salts.

Caroline. How beautiful they are in colour, form, and transparency!

Emily. Nothing can be more striking than this example of chemical attraction.

Mrs B. The term *attraction* has been lately introduced into chemistry as a substitute for the word *affinity*, to which latter name some chemists objected, because it originated in the vague notion that chemical combination depended upon a certain resemblance or relationship between the particles of the different bodies that are disposed to unite; an idea more fanciful

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43. How are the attractions of cohesion and of composition distinguished?
44. What do they respectively unite?
45. What experiment may we perform to exhibit the nature of chemical attraction?
46. What powers has the acid in this case to overcome?
47. What are the striking changes produced?

than just. Without discussing this point very minutely, let it be agreed that we may use the terms *affinity*, *chemical attraction*, and *attraction of composition*, indifferently, provided we recollect that they have all the same meaning (48).

Emily. I do not conceive how bodies can be *decomposed* by chemical attraction. That this power should be the means of composing them is very obvious; but that it should, at the same time, produce exactly the contrary effect, appears to me very singular.

Mrs B. To decompose a body is, you know, to separate its constituent parts, which, as we have just observed, cannot be done by mechanical means.

Emily. No: because mechanical means separate only the integrant particles; they act merely against the attraction of cohesion, and only divide a compound into smaller parts.

Mrs B. The decomposition of a body is performed by chemical powers. If, to a body composed of two principles, you present a third, which has a greater affinity, or attraction, for one of them than the two first have for each other, it will be decomposed, that is, its two principles will be separated by means of the third body (49). Let us, to illustrate this point, take a portion of common soap, which consists of oily matter or fat, united to an alkali. You know that soft soap is made by boiling grease and ley together; this ley contains the alkali called potash, which, uniting with the grease, forms soap. If I drop a portion of any strong acid into some soap suds, the soap will be decomposed, because the acid has a stronger affinity for the alkali than the latter has for the grease.

I will now drop some nitric acid into these soap suds: you see the grease immediately separated, and appearing like oil upon the surface (50).

Caroline. That is a very satisfactory experiment; but as the nitric acid and the potash have united, I should like to know what new compound is formed by their combination.

Mrs B. They have formed a kind of salt, which the chemist calls *nitrate of potash*, and which you know as nitre or saltpetre (51).

Emily. Could we contrive, by any means, to separate the saltpetre from the water and the grease? I should be delighted to be able to do this.

Mrs B. Were we to drop in just enough acid to decompose the whole of the soap, we might then separate the grease, and, on evaporating the water, we should obtain crystals of common nitre (52).

Caroline. And can you decompose the sulphate of copper, and as readily and plainly restore the copper to its natural state, as you did the grease in the last experiment?

Mrs B. Very readily indeed. When we wish to decompose the compound we have just formed by the combination of the two ingredients, copper and sulphuric acid, we may do it by putting into the liquid a piece of iron, for which metal the acid has a stronger attraction than for copper; the acid will, consequently, quit the copper to combine with the iron, and the copper will be, what the chemists call, *precipitated;* that is to say, it will be separated and descend to the bottom of the vessel (53), and appear in its simple form.

In order to produce this effect, I shall dip the blade of this knife into the fluid, and, when I take it out, you will observe that instead of being wetted

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48. What three terms are used synonymously?
49. How may a body composed of two principles be decomposed?
50. Furnish the example given.
51. What new combination is formed?
52. How could this salt be separated?
53. What is meant by *precipitation?*

with a bluish liquid, like that contained in the glass, it will be covered with a thin coat of copper (54).

Caroline. So it is really! but then is it not the copper, instead of the acid, that has combined with the iron?

Mrs B. No; you are deceived by appearances: it is the acid which combines with the iron, and in so doing, deposites or precipitates the copper on the surface of the blade; and were we to allow the blade to remain in the fluid for some time, the whole of the copper would be separated from the acid, a corresponding portion of the iron being dissolved, and forming by its union with the acid *sulphate of iron*, or common copperas(55).

Emily. But cannot three or more substances combine together, without any of them being precipitated?

Mrs B. This very frequently occurs, and in the course of our inquiries you will meet with several examples. There are, for instance, but few rocks or stones which do not consist of more than two ingredients chemically combined together. All salts, also, and indeed the greater number of chemical compounds, may be resolved into three or more simples(56).

Caroline. But pray, Mrs B., what is the cause of the chemical attraction of bodies for each other? It appears to me more extraordinary, or unnatural, if I may use the expression, than the attraction of cohesion, which unites particles of a similar nature.

Mrs B. Chemical attraction may, like that of cohesion or gravitation, be one of the powers inherent in matter, which, in our present state of knowledge, admits of no other satisfactory explanation than an immediate reference to a divine cause(57). Some plausible and ingenious theories have been devised upon this, as well as upon almost every other subject; but until you are acquainted with all the known facts, and your judgments have become matured by time and reflection, such speculations, instead of increasing your knowledge, would retard your progress. Of causes, we may aver that we really know nothing. We say, indeed, that gravitation *causes* a stone to descend; but if we inquire what *causes* gravitation, we find that upon this point we have arrived at the end of our natural philosophy, and are compelled to resolve the whole into the will of the Creator (58).

Emily. The subject of affinity appears to me to be very curious and interesting, and I should like to know a great deal more about it before we enter upon any other. Although your examples seem to be very clear, I can yet scarcely comprehend how the same power should produce combination and decomposition.

Caroline. Let me try whether I cannot explain it by what appears to me to be a striking simile. I hold this apple in my hand, but some one stronger than I am might take it from me; and so a third or a fourth might in succession obtain it, and each by the same kind of power, but different in degree(59).

Mrs B. Your simile is a very happy one, and I am pleased to find you both so much interested in the subject of the attraction of composition. We might devote a considerable portion of time to the laws which obtain in the

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54. How can the copper of the sulphate of copper be separated?
55. What becomes of the iron?
56. Are there many instances in which more than two simples combine to produce a new substance?
57. Are we acquainted with the cause of chemical attraction?
58. Can we, properly speaking, be said to know the cause of any natural phenomenon?
59. By what simile is the power of attraction in producing decomposition illustrated?

chemical combination of bodies; but as every process which I shall either perform or explain, will serve to exemplify one or more of these laws, I shall have ample and better opportunities of rendering them familiar, than by dwelling upon them now. Some of them I shall reserve until you have acquired a considerable portion of knowledge in the elements of chemistry.

Before passing to another subject, I will explain to you the acceptation in which the term *elective* is used by chemists.

Elective affinity, or *elective attraction*, you will find spoken of in every work upon chemistry. The word *elective* is employed to express the choice which any particular substance seems to make in uniting to one body in preference to another, although it may actually possess an affinity to each. It is, therefore, only another form of expressing the fact, that *a body possessing an attraction towards a number of others, possesses it in different degrees*(60).

Emily. I am afraid that I shall never be able to remember what bodies attract each other with the greatest force, and without this I shall never know by what means to separate any two substances which have combined together.

Mrs B. The most able chemists do not pretend to recollect all the facts upon this subject; but they have constructed tables in which the several substances with which a particular body will combine, are placed in the order of their attractions(61), as may be seen in this example, in which is shown the affinity of nitric acid for several of the metals.

Nitric Acid.
Iron,
Lead;
Copper,
Mercury,
Silver.

Here nitric acid (aqua fortis) is placed at the top of the column, and underneath it are some of the metals which it will dissolve, in the order of their affinity. That is, the nitric acid has a stronger attraction for iron than for any one of the metals below it, so that if one of these four were dissolved in the acid, it would be precipitated by the iron. In like manner lead would precipitate the three placed below it.

Again, suppose the silver, which has the weakest affinity for the acid, to be dissolved by it; if we then put some mercury into the solution, this would be dissolved and the silver thrown down. Were we then to put in a piece of copper, that would be dissolved and the mercury precipitated; and in like manner the other metals would precipitate each other in their regular order; but neither of the upper metals would be affected by those below it(62).

Tables of this kind are denominated tables of simple affinity, and they are, as you must perceive, of great use to the chemist.

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60. The term *elective* attraction is frequently used; what is intended by it?

61. What means have been devised for aiding our inquiries on elective attraction?

62. Explain the nature of the example given.

CONVERSATION II.

ON IMPONDERABLE AGENTS.

Chemical Agents divided into Ponderable and Imponderable. Light and Heat capable of separation. Chemical effects of Light. Combination with compound bodies. Phosphorescence. Caloric. Heat, its sources. Free and combined Caloric. Tendency of Heat to Equilibrium. Slow Communication and Radiation. Good and bad Conductors.

Mrs B. Our last conversation has introduced you to some acquaintance with the general principles of chemistry, and with that species of attraction, by which substances, differing in their nature, are induced to combine together, and form a third body, possessing new properties. We now leave the subject of chemical attraction, or affinity, for a short period; but must not finally dismiss it without some addition to the general observations which have already been made. You will be better prepared to resume it after you have acquired some knowledge of the particular properties of a few of the most important substances in their simple forms, and with those agents which the chemist denominates *imponderable;* for besides the division of bodies into simple and compound, the objects of chemical inquiry are further divided into *ponderable* and *imponderable,* or such as are capable of being weighed, and such as do not appear to possess any weight(1).

Caroline. That appears to me to be a strange division. I thought that all matter was ponderable, and that one of its universal attributes was gravitation; but it seems that in learning chemistry we must forget our natural philosophy, and invest matter with new and contradictory properties. Can there be such a thing as matter without weight?

Mrs B. Your remarks are certainly acute, but still you appear to be a little too ardent. Of one thing you may be assured, that any seeming contradiction in the laws of nature serves only to prove the imperfection of our own knowledge. The imponderable agents are *light, heat,* and *electricity,* including *galvanism* and *magnetism*(2). We denominate them imponderable, not because we are certain that they are without weight, but simply because we are not able to weigh them(3); just as we call a body simple, because it has not been decomposed.

Emily. Is it not possible that these imponderable bodies may, in fact, be no bodies at all, but something quite distinct from common matter, in which case it would not be at all surprising that we could not weigh them?

Mrs B. I have used the term *agents,* because some philosophers are of opinion that the imponderables are not really matter itself, but like motion, merely properties of matter(4). They cannot be collected together, confined, and exhibited in masses like ponderable matter: and hence the phenomena which they present have been supposed to result from certain vibratory motions amongst the particles of bodies(5). In many res-

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1. The objects of chemical inquiry are divided into two classes other than simple and compound, what are they ?
2. Name the *imponderable* agents.
3. Do we know that they are absolutely imponderable ?
4. Why is the term *agents* applied to them ?
5. In what way have they been supposed to act ?

pects, however, they exhibit properties and produce effects so analogous to those of matter in general, that, disregarding theoretical opinions, we may safely consider them as material, although extremely subtile, and apply to them the same language which we use in treating of other agents(6). I shall begin with LIGHT, and then pass to the subject of heat, with which it is most intimately connected.

Caroline. I recollect that, in our natural philosophy, light was spoken of as a substance, which emanated from the sun and all other luminous bodies, being projected from them with prodigious velocity, in particles of extreme minuteness(7); and it has always appeared to me that the same might be said of heat, or rather that light and heat were the same thing, only affecting different senses.

Mrs B. Whether light and heat be altogether different agents, or not, I cannot pretend to decide; but, in many cases, light may be separated from heat(8). The first discovery of this fact was made by a celebrated Swedish chemist, named Scheele. Another very striking illustration of the separation of heat and light was long after pointed out by Dr Herschel, whose experiments were published in the year 1800(9). This philosopher discovered that these two agents, though emitted together in the rays of the sun, are not equally refrangible, but that heat was less so than light; for, in separating the different coloured rays of light by a prism (as we did some time ago,) he found that the greatest heat was out of the spectrum, at a little distance beyond the red rays, which, you may recollect, are the least refrangible. Where there is no light whatever, therefore, we find the greatest heat; and throughout the whole of the spectrum, the illuminating and heating effects of the rays bear a different proportion to each other(10). Although the heat is refracted as well as the light, yet, from its being less refrangible, the heating power of each ray decreases as you approach the extreme violet.

Emily. I should like to try that experiment.

Mrs B. It is by no means an easy one: the heat of a ray of light, refracted by a prism, is so small, that it requires a very delicate thermometer to distinguish the difference of the degrees of heat within and without the spectrum. For in this experiment the heat is not totally separated from the light, each coloured ray retaining a certain portion of it, though a great part is not sufficiently refracted to fall within the spectrum(11).

There is, however, a very striking experiment in proof of the separability of heat and light, which you may very easily try. If you take a perfectly clear pane of glass, it will allow the rays of light to pass through with very little diminution of their intensity; yet such a glass will arrest nearly the whole of the radiant heat. To prove this, place your face near to the fire, then suddenly interpose the glass between the two, and although the light will not be sensibly obscured, the heat will appear to be entirely arrested(12).

Emily. But what becomes of the heat in this case; is it reflected back again by the glass into the fire?

Mrs B. By no means, it is absorbed by the glass, which, consequently,

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6. What reason is assigned for treating them as matter?
7. How is *light* treated of in natural philosophy?
8. What is said respecting the connexion between light and heat?
9. To whom are we particularly indebted for experiments on this subject?
10. What particular facts are mentioned?
11. What difficulty is there in the experiment?
12. How is the general fact easily proved?

becomes rapidly heated, and will soon begin to give out the heat which it has acquired, as you will find by continuing it in its situation(13).

Caroline. It certainly appears, very plainly, that light and heat can be separated from each other, but may they not, after all, be essentially the same? for light, which you call a simple body, may be divided into rays variously coloured. It is not clear to me, therefore, that heat is not merely a modification of light.

Mrs B. That is a supposition which, in the present state of natural philosophy, can neither be positively affirmed nor denied. Let us, therefore, instead of discussing theoretical points, be contented with examining what is known respecting the chemical effects of light(14).

Light is an agent capable of producing various chemical changes. It is essential to the welfare both of the animal and vegetable kingdoms; for men and plants grow pale and sickly if deprived of its salutary influence. It is likewise remarkable for its property of destroying colour, which renders it of great consequence in the process of bleaching(15).

Emily. Is it not singular that light, which in studying optics we were taught to consider as the source and origin of colours, should have also the power of destroying them?

Caroline. It is a fact, however, which we every day experience; you know how it fades the colours of linens and silks(16).

Emily. Certainly. And I recollect that endive and celery are made to grow white instead of green, by being covered up so as to exclude the light. But by what means does light produce these effects(17)?

Mrs B. This I cannot attempt to explain to you until you have obtained a further knowledge of chemistry; for the chemical properties of light can be accounted for only in its relationship to compound bodies, of which bodies we shall, in the greater number of instances, find light to form a constituent part, and that it is frequently given out during their decomposition(18).

Emily. I should like very much to see a body decomposed, and the light given out from it; can you show us any experiment of this kind?

Mrs B. It is an experiment of this kind which now enables you to see me and all the articles in the room; and you witness such decompositions every night of your life.

Caroline. Thank you Mrs B. for the hint; and now let me try if I cannot explain the fact to which you allude. Light, I suppose, forms one of the constituents of tallow and oil, which are decomposed in burning, and the light given out(19).

Mrs B. Very good, indeed; your explanation, so far as it goes, is complete. The light given out by burning bodies, or by those which are strongly heated, is called artificial light; whilst that given out by the sun and stars is called natural light. These two kinds of light differ sufficiently, particularly in their chemical properties, to render it proper to distinguish them from each other, and to recollect that, in general, when we speak of the influence of light, we mean natural light—light as it comes to us in the solar ray(20).

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13. What becomes of the heat?
14. Is it certain that light and heat are essentially distinct?
15. Enumerate some of the chemical effects of light.
16. Give examples of the bleaching property of light.
17. Does its exclusion ever render bodies white?
18. What is said respecting light and some compound bodies?
19. Whence comes the light in the burning of candles, &c.?
20. What particular distinction is mentioned respecting light?

Emily. I should be glad to know some p[illegible]lars in which these two kinds of light differ from each other; I should [illegible]ve thought that they were the same, excepting in their intensity.

Mrs B. The differences between them belong, in general, to a more advanced stage of our subject, and we must anticipate as little as possible. There is one point of difference, however, which may be shown by this simple pane of glass. When the rays of light and heat from an artificial source met the glass, you found that but little of the heat passed through it; but, in the solar ray, nearly the whole of the heat accompanies the light in its transmission through it(21).

Caroline. It seems to me that there must be some other source of natural light besides the sun and stars, as there are some substances which always shine in the dark.

Mrs B. Light is capable of entering into a kind of transitory union with certain substances, and thus giving to them what has been called phosphorescence. Bodies that are possessed of this property, will, after being exposed to the sun's rays, appear luminous in the dark. The shells of fish, the bones of land animals, marble, limestone, and a variety of combinations of earths, are more or less phosphorescent(22).

Emily. I remember being much surprised last summer with the phosphorescent appearance of some pieces of rotten wood, which had just been dug out of the ground: they shone so brightly as to appear to be actually on fire. The light of the fire-fly, I suppose, is also of a phosphorescent nature.

Mrs B. It is a very remarkable instance of phosphorescence in living animals. This property, however, is not exclusively possessed by the fire-fly. There are in the West Indies, and in South America, some larger insects which emit a light so brilliant, that three or four of them will suffice to enable a person to read in a place otherwise dark(23).

Emily. But is it certain that in all cases of phosphorescence the light proceeds from the same cause? The difference between a piece of dead wood and a living animal is so great as to make it difficult to believe this.

Mrs B. It certainly is not probable that the cause is the same, although there is a similarity in the results. Dead animal matter frequently emits light, and this, it is probable, is a consequence of its decomposition, and may therefore be analogous to that given out in combustion(24).

Emily. I have heard that the sea has sometimes the appearance of being illuminated, and that the light is supposed to proceed from the spawn of fishes floating on its surface.

Mrs B. This light is probably owing to that or some other animal matter. Sea water has been observed to become luminous from the substance of a fresh herring having been immersed in it; and certain insects, of the Medusa kind, are known to produce similar effects. There, in fact, appear to be several different sources of the luminousness of the ocean(25).

But the strongest phosphorescence is produced by certain chemical compositions prepared for the purpose, and called solar phosphori, the most common of which consists of oyster-shells and sulphur, calcined together in a crucible; this kind is known by the name of Canton's phosphorus.

To cause any of the solar phosphori to appear luminous, they are put into a well stopped phial, and after being exposed to the direct light of the sun, they shine in the dark for some minutes with a brilliancy sufficient to

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21. Give an evidence of the difference in the two.
22. Give examples of phosphorescence.
23. What is noticed respecting phosphorescence in insects?
24. Is it probable that this light is always produced in the same way?
25. What is said respecting the luminous appearance of the sea?

show the time by a watch. By degrees they cease to shine, but again do so as often as they are exposed to the light(26).

Caroline. Light, in this case, appears to operate very much like heat. If I warm a body and remove it to a cool place, the heat will pass off, and this I can repeat again and again.

Mrs B. There is certainly a striking resemblance between the two in this particular, and it has been used as an argument by those who do not believe heat and light to be distinct material substances. The particles of light seem to adhere to these phosphori with a certain degree of force, and gradually to fly off, and, as it were, to evaporate(27). But it is time for us to pass on to the examination of heat, or caloric, which, as it is the most powerful of all the chemical agents, will demand a considerable share of attention.

HEAT and LIGHT may be always distinguished by the different sensations they produce. *Light* affects the sense of sight; *heat*, or *caloric*, that of feeling; the one produces *vision*, the other the sensation of *warmth*(28).

Caroline. It seems to me quite unnecessary and embarrassing to call the same thing by two names; and this is evidently the case with the chemists who have introduced the term *caloric*, which you have just used as synonymous with heat(29).

Mrs B. You are, in the present instance, both too prompt and too confident in your judgment. The term *caloric* was introduced, because philosophers, as well as the vulgar, were in the habit of calling two distinct things by the same name.

The *cause*, caloric, and the *effect*, heat, were confounded together under the same denomination, whilst they are, in fact, as distinct and different from each other as are *light* and *vision*(30). Although this distinction has been made, the chemist frequently departs from its strict observance, often using the word heat to designate the operating agent, as well as the effect which it produces. In conformity with universal custom, also, we speak of the heat of inanimate matter, as *the heat of an oven*, or *the heat of the sun*, without any reference to the sensation which it is capable of exciting(31). Caloric, you will hereafter find, may exist in a body without increasing its temperature, and of course it is in such a case imperceptible to us(32).

Emily. It must be a very strange kind of heat that cannot be perceived by our senses, which seem to be the only means by which we know of its existence.

Mrs B. Light has been spoken of as combining with bodies, and forming a part of their substance; and whilst in this state, its power of exciting vision is suspended. In like manner heat may combine with, and form part of a compound; and whilst so combined, it will not excite any sensation in us(33). If I touch a warm body, it is the caloric which passes from that body into my hand which produces the sensation of warmth; if the caloric were combined with, and did not leave the body, it would not produce any effect upon me(34).

Caroline. There are, therefore, two entirely different modifications of caloric; one in which it produces heat, and another in which it does not.

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26. What of solar phosphori?
27. What analogy is noticed between light and heat?
28. By what properties are light and heat distinguished?
29. What term is used by the chemist as synonymous with heat?
30. What distinction exists strictly between *caloric* and *heat?*
31. Is this distinction always observed?
32. What is said of caloric, without heat?
33. What analogy is there between light and heat in this particular?
34. How does a warm body produce the sensation of heat?

Mrs B. We are acquainted with three distinct sources of heat. The sun you know as the great and principal source; but we also derive it from mechanical and from chemical action. Friction, or the rubbing of two solid bodies together, and percussion, are examples of the former, and combustion is a familiar one of the latter(35).

Caloric is found also to exist under a variety of forms or modifications; your attention, however, will be directed to it under the two principal, which are

1. Free or Radiant Caloric,
2. Combined Caloric, called also Latent Heat(36).

The first, FREE OR RADIANT CALORIC, is also called SENSIBLE HEAT, or HEAT OF TEMPERATURE; it comprehends all heat which is perceptible to the senses, and affects the thermometer.

Emily. You mean such as the heat of the sun, of fire, of candles, of stoves; in short, of every thing that burns?

Mrs B. And likewise of things that do not burn, as, for instance, the warmth of the body; in a word, all heat that is *sensible,* whatever may be its degree, or the source from which it is derived(37).

In examining into these modifications, we shall consider heat or caloric as material, and capable of increase or diminution in a body(38). This being admitted, it will appear to be a subtile fluid, the particles of which repel each other, and are attracted by all ponderable substances; and that it is present in all bodies, however low their temperature(39). That the last is a fact, you can readily conceive; as it is easy to imagine the temperature of a body to be reduced still lower than it is, which could take place only by its parting with caloric(40).

Caroline. I am quite impatient to learn every thing respecting your second modification; as to sensible heat, it already seems to be familiar to me, but your *insensible caloric* is quite a new subject.

Mrs B. I thought we were to proceed methodically; if we do not, you will soon become involved in a labyrinth, whence you will scarcely be able to extricate yourselves. On the subject of free caloric, or sensible heat, you have much to learn. Your attention will be directed, 1st, to the universal tendency of free caloric to an equilibrium; 2d, to the manner in which this tendency is exerted; and 3d, to the effects produced upon bodies by its entrance into them(41).

Emily. The first division seems to include a contradiction of known facts, for if there be a constant tendency in all bodies to the same temperature, it seems to me that they must have long since arrived at it.

Mrs B. Your remark is specious, but not solid. Water has a constant tendency to find its level, yet there is a perpetual flux and reflux of the tides in the sea, and in rivers, because there are disturbing causes which counteract this tendency; and the same is the case with heat. The sun supplies his rays by day, and they are withdrawn at night; clouds, winds, rain, and a thousand mechanical and chemical changes alter the temperature of bodies; you are familiar with this fact in combustion, and will hereafter become acquainted with it in numerous other instances(42). This ten-

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35. What are the three sources of heat?
36. What are the two principal modifications of caloric?
37. What is said of free or radiant heat?
38. How is heat considered, in regard to its nature, in these conversations?
39. What kind of fluid will it then appear to be?
40. What may we suppose to justify the last conclusion?
41. The subject of free caloric is treated under three heads, name them.
42. What prevents an actual equilibrium of temperature?

dency to an equilibrium serves to correct these disturbing causes, and both co-operate in producing and perpetuating that harmonious variety which so delightfully diversifies our days and our seasons(43).

Caroline. But if this equilibrium is never attained, I do not see how we can infer the universal prevalence of a tendency towards it. Water seeks its level because it gravitates, but caloric is *imponderable*, and therefore is without that property which actuates water, in the tendency of which we are speaking(44).

Mrs B. Very true, Caroline, that is an excellent objection. You might also, with some propriety, object to the term *equilibrium* being applied to a body that is without weight; but I know of no expression that would explain my meaning so well. You must understand it, however, in a figurative rather than a literal sense: its strict meaning is an *equal diffusion*(45). We have already considered the particles of caloric as repulsive of each other, and as attracted by other bodies, and these properties may afford us some light upon the subject we are considering. Where there is most caloric there will be most repulsion, and of course the caloric of a warmer body must, by this repulsion, be disposed to leave that body and unite with a colder. The proofs of this tendency are numerous and complete(46). If we place a hot piece of iron in contact with one that is cold, the former will rapidly lose, and the latter acquire heat, and in a short period they will both have arrived at the same temperature. If a number of substances, different in temperature, be enclosed in an apartment in which there is no actual source of caloric, they will very soon acquire an equilibrium, so that a thermometer placed in contact with either of them will indicate the same temperature(47).

Emily. Although I have no doubt of the fact, I am at a loss to perceive how this equilibrium is produced, especially when the warm and the cold bodies are at a distance from each other.

Mrs B. Heat passes from one body to another in two ways: first, by what is sometimes called the slow communication, or *conducting* power, and second, by *radiation*, or rapid communication(48). When bodies of different temperatures are in contact with each other, it is *conducted* from one to the other; when they are placed at a distance, it is *radiated.* If you place your hand upon a heated body, the former takes place; if you stand before the fire, or in the sunshine, you receive heat by radiation. These two causes constantly operate in diffusing caloric. Thus the fire which burns in the grate, communicates its heat from one object to another, till every part of the room has a portion of it(49).

Emily. And yet this book is not so cold as the table on which it lies, though both are at an equal distance from the fire, and actually in contact with each other; but according to your theory, they should be exactly at the same temperature.

Caroline. And the hearth, which is much nearer the fire than the carpet, is certainly the colder of the two(50).

Mrs B. If you ascertain the temperature of these several bodies by a

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43. What benefits result from this tendency?
44. What objection is urged?
45. What to the term *equilibrium?*
46. How is the tendency to *equal diffusion* exerted?
47. Give the examples.
48. By what two means is heat diffused?
49. Give the exemplifications.
50. What objection is urged?

thermometer (which is a much more accurate test than your feeling,) you will find that it is exactly the same in all(51).

Caroline. But if they are of the same temperature, why should the one feel colder than the other?

Mrs B. The hearth and the table feel colder than the carpet or the book, because the latter are not such good *conductors of heat* as the former. Caloric finds a more easy passage through marble and wood, than through leather and worsted; the two former will therefore absorb heat more rapidly from your hand, and consequently give it a stronger sensation of cold than the two latter, although they are all of them really of the same temperature(52).

Caroline. So, then, the sensation I feel on touching a cold body, is in proportion to the rapidity with which my hand yields its heat to that body.

Mrs B. Precisely; and if you lay your hand successively on every object in the room, you will discover which are good, and which are bad conductors of heat, by the different degrees of cold which you feel. But in order to ascertain this point, it is necessary that the several substances should be of one uniform temperature, which will not be the case with those that are very near the fire, or those that are exposed to a current of cold air from a window or door(53).

Emily. But what is the reason that some bodies are better conductors of heat than others?

Mrs B. That is a point not well ascertained. In general the most dense bodies, as the metals, are the best conductors, whilst those which are light and porous are bad conductors; and this undoubtedly arises, in part, from the points of contact being more numerous in dense bodies than in those that are more rare. From this cause iron filings conduct heat more slowly than the solid metal. This, however, is not the sole cause, as the conducting power is not always proportioned to the density(54).

Whatever may be the causes which operate in producing this difference in conducting power, you now clearly understand, that the passage of caloric through bodies that are good conductors, is much more rapid than through those that are bad conductors; and that the former both give and receive it more quickly, and therefore in a given time more abundantly, than bad conductors, which makes them feel either hotter or colder, though they may, in fact, both be of the same temperature.

Caroline. Yes, I understand it now; the table and the book lying upon it, being really of the same temperature, would each receive in the same space of time, the same quantity of heat from my hand, were their conducting powers equal; but as the table is the best conductor of the two, it will absorb the heat from my hand more rapidly, and consequently produce a stronger sensation of cold than the book, as it is the heat which my hand loses that causes it to feel cold(55).

Mrs B. Very well, my dear; and observe, likewise, that if you were to heat the table and the book an equal number of degrees above the temperature of your body, the table, which before felt the colder, would now feel the hotter of the two; for, as in the first case it took the heat most rapidly from your hand, so now it will most rapidly impart heat to it. Thus the marble table, which seems to us colder than the mahogany one, will prove

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51. How is the objection removed?
52. Why is the sensation of heat different from bodies of the same temperature?
53. How may good and bad conductors be detected?
54. What is said of the cause of this difference?
55. Give the illustrations.

the hotter of the two to a piece of ice placed upon it; for, if it takes heat more rapidly from our hands, which are warmer than itself, it will give out heat more rapidly to the ice, which is colder. Do you understand the reason of these apparently opposite effects(56)?

Emily. Perfectly. A body which is a good conductor of caloric, affords it a free passage, so that it penetrates through that body more rapidly than through one which is a bad conductor; consequently, when I place my hand in contact with a good conductor, if the body touched be colder than the hand, it loses more caloric, in a given time; and if it be hotter, gains more than it would do were the substance a bad conductor and at the same temperature(57).

Mrs B. But you must observe that this is the case only when the conductors are either hotter or colder than your hand: for, if you heat different conductors to the temperature of your body, they will all feel equally warm, since the exchange of caloric between bodies of the same temperature is equal(58). Now, can you tell me why flannel clothing, which is a very bad conductor of heat, prevents our feeling cold?

Caroline. It prevents the cold from penetrating ——

Mrs B. But you forget that cold is only a negative quality; we do not suppose that any thing more is requisite to cause a body to become cold, than merely for the heat to pass out of it.

Caroline. True, it only prevents the heat of our bodies from escaping so rapidly as it would otherwise do.

Mrs B. You have explained it correctly; the flannel rather keeps in the heat than keeps out the cold(59). Were the atmosphere of a higher temperature than our bodies, it would be equally efficacious in protecting them against an increase of temperature, as it would prevent the free access of the external heat, by the difficulty with which it conducts it.

Emily. This, I think, is very clear. Heat, whether external or internal, cannot easily penetrate flannel; therefore in cold weather it keeps us warm, and if the weather were hotter than our bodies, it would keep us cool.

Mrs B. You now perceive the reason why we wrap a heated brick or a lump of ice in flannel, to cause the first to retain its heat, and to prevent the latter from thawing.

Caroline. O yes, that I understand perfectly; the atmosphere is colder than the brick, and would rob it of its heat, but it is warmer than the ice, and would therefore communicate heat to it and so cause it to melt; these effects the flannel prevents, by keeping the heat from passing outwards from the brick, and inwards from the air to the ice(60).

Mrs B. We have already remarked that the most dense bodies are usually the best, and the lighter bodies the worst conductors of caloric. Air, which has but little density, is known to be a very bad conductor, and this is undoubtedly one great reason why light, fibrous materials, such as flannel, fur and down are very bad conductors, as they contain a considerable quantity of air entangled between their fibres. Down, which is the lightest and the most fibrous, is the worst conductor, or, as you would say, makes the warmest covering(61).

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56. What is remarked of substances heated above the temperature of the body?
57. Give Emily's explanation.
58. What is the operation of bodies at equal temperatures?
59. How does flannel operate in keeping us warm?
60. For what apparently opposite purposes are bad conductors used?
61. Why are light fibrous materials bad conductors?

Caroline. This is, I suppose, the reason why the plumage of birds preserves them so effectually from the influence of cold in winter?

Mrs B. Yes; feathers in general are an excellent preservative against cold; but aquatic birds have a kind of plumage peculiar to themselves, covering their breasts, which is the part most exposed to cold; for though the surface of the water is not of a lower temperature than the atmosphere, yet, as this fluid is a better conductor of heat, it feels much colder; consequently the breast of the bird requires a warmer covering than the upper part of its body(62).

Most animal substances, especially those which Providence has assigned to them as a covering, such as fur, wool, hair, silk, &c. are bad conductors of heat, and are, on that account, such excellent preservatives against the inclemency of winter, that our warmest apparel is made of these materials(63).

Emily. Wood is, I dare say, not so good a conductor as metal, and it is for that reason, no doubt, that silver tea-pots have always wooden handles.

Mrs B. You are correct, and as is the case in the fibrous materials used for clothing, it is probable that the air contained in the pores of the wood tends much to lessen its conducting power(64).

Caroline. It is a very fortunate circumstance that air should be a bad conductor, as otherwise the heat of the body, when exposed to cold weather, would be rapidly carried off.

Mrs B. This is one of the many benevolent dispensations of Providence, in order to soften the inclemency of the seasons, and to render almost all climates habitable to man(65).

The power of conducting heat varies likewise very remarkably in fluids of different densities. If you dip your hand into this vessel of mercury, you will scarcely be able to conceive that its temperature is not lower than that of the atmosphere.

Caroline. Indeed it is difficult to believe that it is not, it feels so extremely cold. But we may easily ascertain its true temperature by the thermometer. It is really not colder than the air; the apparent difference then is produced merely by the difference of the conducting power in mercury and in air(66).

Mrs B. Yes; and hence you may judge how little the sense of feeling is to be relied on as a test of the temperature of bodies, and how necessary for that purpose is a thermometer.

To show you the fallacy of our judgment of temperature when guided by the sense of feeling alone, I have placed water of three different temperatures in these three bowls; that to your left contains ice; the water in the one to your right is heated so that you can just bear to hold your hand in it, and that in the middle bowl is at about the temperature of your body. Now hold one hand in the hot, and the other in the iced water for some time, and then plunge them both into the middle bowl.

Emily. Oh! To my left hand it feels as if the water was very much heated, and to my right, like the iced water. One hand declares it to be cold, and the other to be warm; which shall I believe(67)?

Caroline. Neither; but let us both always recollect, that we are endowed with reason as well as with sensation, and that we should rarely allow

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62. What is remarked respecting aquatic birds?
63. What of our warmest apparel?
64. What respecting wood?
65. What respecting air?
66. Give the exemplification of the difference in fluids.
67. Relate the experiment with three bowls?

the latter to guide us until its conclusions are sanctioned by the former. This, I well know, is a lesson which I very much need to learn(68).

Since we are now so fully convinced of the fallacy of the sense of feeling in ascertaining the real temperature of a body, and shall be compelled to resort, perpetually, to the thermometer, I should like to know something more than I do respecting the principle upon which that instrument acts.

Mrs B. We will soon attend to that, but you are not yet quite prepared to enter upon the subject, and in the mean time you can advantageously employ the thermometer, as you know that the rise and fall of the mercury indicates corresponding changes in temperature. We have not yet done with the conducting power of bodies, nor have we examined the subject of radiation; and before proceeding further you will do well to ruminate upon what has been already explained, and we will resume its further consideration to-morrow.

CONVERSATION III.

FREE CALORIC CONTINUED.

Difference in the Conducting Power of Bodies. Fluids the worst Conductors. Radiation of Caloric. Pictet's Experiments. Radiating Power of different surfaces. Power of absorbing different in different surfaces. Distinction between Radiation and Reflection.

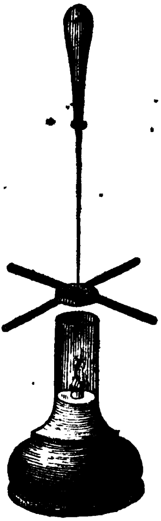
Mrs B. There are many easy and striking experiments which manifest the difference in the conducting power of different solids; after attending to two or three of these, you must learn something of the manner in which heat is distributed through fluids.

If you place one end of a rod of iron in the fire, you will find that the heat passes with comparative quickness to the other extremity, whilst a piece of wood of the same size may be burnt nearly its whole length without any sensible conveyance of heat along it(1).

Here is a pin and a small strip of glass about equal in size and length; now, Emily, take these together in your fingers and hold one end of each in the flame of the candle.

Emily. See, I have been compelled to let the pin fall; it was too hot to hold, yet I do not feel the glass warm, although the end in the flame has melted(2)!

Mrs B. Because glass is a very bad conductor, and the metals are very good ones: these latter, however, differ greatly from each other, as this little instrument will show you. Small bars of four different metals, all of equal size, are attached to a piece of brass, which may be heated by holding it over a lamp by means of the handle, and the metal bars will of course become heated. These bars are of silver, copper, iron, and lead; I



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68. What deduction does Caroline draw?

1. Give the example of the difference in the conducting powers of iron and wood.

2. Give that of glass and a common pin.

have dipped each of them into melted wax, and by this I have cemented a piece of card to the end of each. We shall find on heating them that the silver is the best conductor, next the copper, and then the iron, whilst the lead is very inferior to either of the others. Observe the wax is melting first upon the silver;—and now the piece of card has fallen from it.

Emily. The pieces have fallen from each in the order in which you named them, and the difference between them has proved to be much greater than I expected(3).

Mrs B. You have seen that although all solids are conductors of heat, they vary greatly from each other in this respect. In speaking of air it was mentioned as a very bad conductor, and you are to understand the same of all fluids, whether elastic or non-elastic(4). That distinguished philosopher, Count Rumford, who investigated this subject with much care, considered fluids as being absolutely non-conductors, and believed that if their particles could be kept from motion among themselves, it would be impossible to heat them throughout(5).

Caroline. How could the Count think so, as we know that they are capable of imparting heat to, or taking it from us, accordingly as they are hotter or colder than we are?

Emily. And how, if the particles of water do not communicate heat to each other, does that which is contained in a vessel over the fire become hot throughout(6)?

Mrs B. Count Rumford admitted that solid bodies would communicate heat to the particles of fluids which were in contact with them, and that fluids would in like manner communicate it to solids, but denied that any such interchange took place between the particles of fluids themselves(7). With respect to Emily's question, the particles of fluids, you know, move with the most perfect facility among themselves, and you are also aware that fluids are expanded by heat, and consequently rendered specifically lighter; it was to these two circumstances that the Count attributed the diffusion of heat in fluids. When a vessel containing water is placed upon the fire, the bottom of it becomes heated, and communicates its heat to the particles of water in contact with it; these becoming expanded, and consequently lighter than the portions above, rise to the surface and leave a new layer of particles to be acted upon in the same way. This change of place continues until the whole of the water has arrived at the boiling point; the heat not being communicated from particle to particle, but *conveyed*, or *carried* by the currents which are established(8).

Caroline. This accounts most ingeniously for the propagation of heat upwards; but supposing you were to heat the upper surface of a liquid, the particles being specifically lighter than those below, could not descend. How, therefore, would the heat be communicated downwards?

Mrs B. Had the Count's assumption been absolutely correct, a liquid could not be heated from above(9); and indeed, although this does take place, it is effected so slowly, that he believed the heat was, in every case, conducted down by the solid vessel in which the fluid must be contained; the effect being more or less slow as this is a good or bad conductor(10).

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3. How may the difference in the conducting power of metals be shown?
4. Are fluids good conductors?
5. What opinion did Count Rumford entertain upon this point?
6. What objections are urged to this opinion of Rumford?
7. How did Rumford suppose heat to operate between solids and fluids?
8. In what way did he suppose that heat was diffused in a fluid?
9. Why would not this account for heat descending in a fluid?
10. How did Rumford suppose the descent to be effected?

It is certain that heat is diffused in liquids principally by the motion among their particles. Although this motion is invisible on account of their extreme minuteness, we can, by a little artifice, manifest the existence of the currents of which I have spoken. If you mix with the liquid any coloured dust, or powder, of nearly the same specific gravity as itself, you may judge of the internal motion of the fluid by that of the coloured dust which it contains. Do you see the small pieces of amber moving about in the liquid contained in this phial?

Caroline. Yes, perfectly.

Mrs B. We will now immerse the phial in a glass of hot water, and the motion of the liquid will be shown by that which it communicates to the amber(11).

Emily. I see two currents, one rising along the sides of the phial, the other descending in the centre; but I do not understand the reason of this.

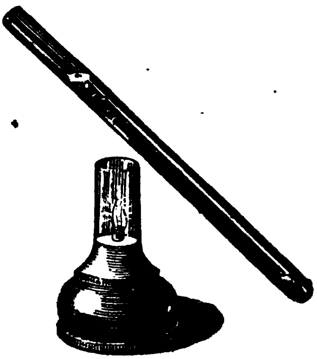
Mrs B. The hot water communicates its caloric, through the medium of the phial, to the particles of the fluid nearest to the glass; these dilate and ascend laterally to the surface, whilst the less heated particles, distant from the surface of the phial, in descending, form the central current(12).

Caroline. This is indeed a very clear and satisfactory experiment; but how much slower the currents now move than they did at first.

Mrs B. It is because the circulation of particles has nearly produced an equilibrium of temperature between the liquid in the glass and that in the phial.

Caroline. It appears, then, that we are to consider liquids themselves as non-conductors.

Mrs B. By no means; for although they are heated principally by means of the mobility of their particles, it has been shown by very satisfactory experiments, that fluids, although the worst conductors known, do absolutely admit of the conveyance of heat, from particle to particle, like solid bodies(13). The term non-conductors of heat cannot therefore be properly applied to any body in nature; whenever you see it used you must therefore understand that it is employed relatively, and not absolutely(14).



In many instances when we wish to diffuse heat equally, and rapidly, we employ fluids for the purpose. This might lead to the conclusion that they are among the best conductors, were not the contrary plainly proved; their adaptation to this purpose resulting from the ready mobility of their particles, as you now understand. One or two striking experiments, however, showing how slowly they conduct heat, will still be of use, as they will impress the fact upon your minds indelibly.

I have nearly filled this glass tube with cold water, and by a weight have confined a piece of ice at the bottom of it. I hold the tube sloping over the flame of a lamp, so as to heat the water in the upper part; this will be soon made to boil, whilst the ice will re-

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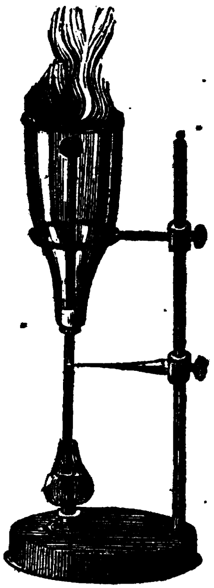
11. By what means may the currents be rendered visible?
12. From what cause will two currents be produced?
13. Are fluids really non-conductors?
14. How is the term non-conductors to be understood?

in below unthawed for a considerable length of time. If we had allowed ice to float upon the surface, and applied the heat below, the ice would re been melted before the water would have become sensibly warm(15).

Caroline. Yes, in that case the water which had become heated below uld have ascended to the surface, when it would have been cooled again its contact with the ice.

Mrs B. This experiment is sometimes varied by putting some coloured er at the bottom of the tube, instead of the ice. The clear water above y be boiled without disturbing the coloured part; but if the heat be ap- d below, the coloured portion will be seen to rise to the surface(16).



The little apparatus which I am now about to exhibits the same fact very satisfactorily. It sists of a very sensible air thermometer, ce- ated into the lower end of a glass, funnel-shap- vessel, so that when the vessel is nearly filled h water, the bulb of the thermometer will be a e below its surface. Upon this water I pour rtion of ether, which will float upon it, and is ry inflammable liquid. I then set fire to the er, and it will continue to burn for a considera- time, without affecting the thermometer, as may ascertain by noticing the pointer, which ws the height at which the coloured liquid ds in the tube(17).

Emily. That is equally extraordinary and sa- actory, and I am sure I shall recollect it when- r I smell ether.

Mrs B. We shall frequently have to recur to slow communication of caloric by the conduct- power of bodies, and will now examine the ond mode by which heat is distributed, which recollect is RADIATION.

Caroline. We have already learned that heat ses off in rays in conjunction with light, both n the sun and from burning bodies; but is it likely that in these instances the light is the ve agent, and carries the heat with it in con- uence of the two being combined together.

Mrs B. By no means: in their property of passing off in rays which re with immense velocity, heat and light appear to be analogous. But this, the calorific rays which were found beyond the confines of those of it in the experiments of Herschel, could not have existed there. You know that if a piece of iron, or any other body, be heated, though not iciently so to emit light even in the dark, you will very sensibly feel the t emanating from it as you approach it; and this, of course, is in conse- nce of radiation(18).

Emily. May not the heat be conducted to us by the atmosphere with ch it is surrounded, and the radiation be in this case merely apparent.

Mrs B. Were you placed above the heated body this might be the case, he air which is heated by contact with the body, having its specific gra- decreased, immediately ascends; but as you feel the heat both laterally

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5. By what experiment may it be shown that fluids are bad conductors?
6. How may this experiment be varied?
7. How may the fact be proved by burning ether?
8. What circumstances prove the *radiation* of heat alone

and downwards, it must pass by radiation alone. The experiments which you will witness on this subject will establish the fact beyond the possibility of a doubt. The cooling of a body is greatly accelerated by the presence of air; but a heated body, though suspended in vacuo, will have its temperature reduced to that of surrounding bodies, and this must be effected by the operation of radiation alone(19).

Caroline. What a constant bustle there must be among the particles of caloric, if they are thus perpetually flying about from one body to another; but I do not see why this should always be the case. If all the bodies in a room are of the same temperature, I do not perceive any effect that is to be produced by radiation, and indeed I should suppose that in that case it does not take place; and yet I do not know how a body on one side of a room should know that there is a cooler body on the opposite side, and consequently begin to radiate(20).

Mrs B. You have unconsciously touched a theoretical question which has divided philosophers. Some have believed that bodies radiate in proportion only to the excess of caloric which they contain above surrounding bodies, and that, as you suggest, if all were of one temperature, radiation would cease, in consequence of the equal tendency of the particles of caloric to fly off. A more generally received opinion however is, that caloric, being composed of particles which are mutually repulsive, is constantly flying off in all directions, with immense velocity(21).

Without pretending to decide the controversy, we will, for the sake of illustration, adopt the latter opinion, and suppose all bodies, whatever their temperature, to be constantly radiating caloric. Those that are of the same temperature give out and absorb equal quantities, so that no variation of temperature is produced in them; but when one body contains more free caloric than another, the exchange is always in favour of the colder body, until an equilibrium is effected(22).

Caroline. This reciprocal radiation surprises me extremely. I at first thought, that the hotter bodies alone emitted rays of caloric, which were absorbed by the colder; and it still seems unnatural that a hot body should receive any caloric from a cold one, even though it should return a great quantity.

Mrs B. It may at first appear so, but it is no more extraordinary than that a candle should send forth rays of light to the sun, which you know, must necessarily happen(23).

Caroline. Well, Mrs B., I believe that I must give up the point. But I wish I could *see* these rays of caloric; I should then have greater faith in them.

Mrs B. You must give some credit to your reason, as well as to your senses, or *faith* is out of the question. Your reason will tell you, that if you gain more heat than you lose, the gain being absolute, the sensation of warmth must be felt. It is, therefore, only when you are parting with it to a body of a lower temperature, that you can experience the sensation of cold, because you then sustain an absolute loss of caloric.

Emily. And in this case we cannot be sensible of the small quantity of heat we receive in exchange from the colder body, because it serves only to diminish the loss(24).

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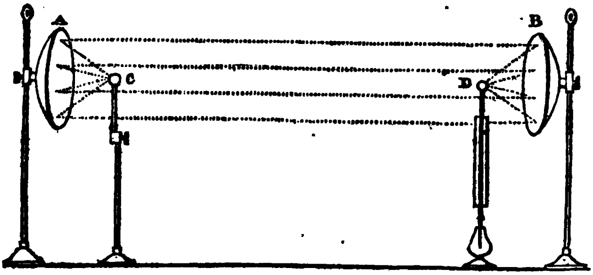
19. What facts prove that the heat is not conducted by the atmosphere?
20. What remarks does Caroline make respecting radiation?
21. What two theories have been maintained respecting radiation?
22. What is the theory adopted in these conversations?
23. What analogy with mutual radiation does light afford?
24. Why do we not always feel the loss of heat by radiation?

Mrs B. Very well, indeed, Emily. Professor Pictet, of Geneva, has made some very interesting experiments, which prove not only that caloric radiates from all bodies whatever, but that these rays may be reflected, according to the laws which govern in the radiation of light(25). I shall repeat these experiments before you, having procured mirrors fit for the purpose; they are, as you see, concave, and made of tin highly polished. Those which I use are a foot in diameter, and their curvature is a radius of nine inches; the focus of parallel rays being, therefore, four and a half inches distant from the centre of each mirror. In the focus of one mirror I place an iron bullet, about two inches in diameter, and heated, but not to a degree sufficient to render it luminous. The rays of heat which fall on it are, agreeably to the property of concave mirrors, reflected in a parallel direction, so as to fall on a similar mirror, which, you see, is placed opposite to the first, and at the distance of about ten feet: this second mirror causes the rays to converge to its focus, in which I place the bulb of this very sensible air thermometer. Now, observe in what manner it is affected by the caloric which is reflected on it from the heated bullet. The air is dilated in the bulb which we placed in the focus of the mirror, and the liquor is, you see, considerably depressed in the tube(26).

Mr Pictet's Apparatus for the Reflection of Heat.



[A. and B, concave mirrors, fixed on stands. C, heated bullet, placed in the focus of the mirror A. D, thermometer, with its bulb placed in the focus of the mirror B. The dotted lines show the course of the rays of heat diverging from the heated ball C, then rendered parallel by the mirror A, whence they are reflected to the mirror B, from which they converge, and fall upon the thermometer in its focus D.]

Emily. But would not the same effect take place, if the rays of caloric from the heated bullet fell directly on the thermometer, without the assistance of the mirrors?

Mrs B. The effect would in that case be so trifling, at the distance at which the bullet and the thermometer are from each other, that it would be almost imperceptible. The mirrors, you know, greatly increase the effect, by collecting the large quantity of rays which falls upon their surface into a focus. Place your hand in the focus of the mirror, and you will find it to be hotter there than in situations much nearer to the bullet.

Emily. That is very true; it appears extremely singular to feel the heat diminish in approaching the body from which it proceeds.

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25. What did Pictet of Geneva prove respecting the radiation of heat?
26. Describe the apparatus used by him for radiation.

Caroline. And the mirror which, by converging the rays, produces so much heat, is itself quite cold.

Mrs B. The whole of the rays that are dispersed over the surface of the mirror are collected by it into the focus; and if you consider how large a surface the mirror presents to the rays, and, consequently, how much they are diffused in comparison with what they are at the focus, which is little more than a point, I think you can no longer wonder that the focus should be so much hotter than the mirror(27).

The mirrors are so used in this experiment as to prove that the calorific emanation is reflected in the same manner as light(28).

Caroline. And the result, I think, is very conclusive.

Mrs B. The experiment may be repeated by substituting a wax taper for the bullet, with a view of separating the light from the caloric. For this purpose a transparent plate of glass must be interposed between the mirrors; for light, you know, passes with great facility through glass, whilst the transmission of artificial heat is almost wholly intercepted by it. We shall find, however, in this experiment, that some few of the calorific rays pass through the glass together with the light, as the thermometer indicates; but, as soon as the glass is removed, and a free passage left to the caloric, it will manifest a considerably higher temperature(29).

Emily. That light and heat may be separated is equally well proved by this experiment as by that of Dr Herschel; for in the latter, the separation was not perfect, any more than in that of Mr Pictet.

Caroline. I should like to repeat this experiment, with the difference of substituting a cold body instead of a hot one, to see whether cold would not be reflected as well as heat.

Mrs B. That experiment was proposed to Mr Pictet by an incredulous philosopher like yourself, and he immediately tried it by substituting a piece of ice in the place of a heated bullet.

Caroline. Well, Mrs B., and what was the result?

Mrs B. That we shall see; I have procured some ice for the purpose.

Emily. The thermometer indicates a considerable reduction of temperature(30)!

Caroline. And does not that prove that cold is not merely a *negative* quality, implying simply an inferior degree of heat? The cold must be *positive,* since it is capable of being reflected.

Mrs B. So it at first appeared to Mr Pictet; but upon a little consideration he found that it afforded only an additional proof of the reflection of heat. This I shall endeavour to explain to you.

According to our theory, we suppose that all bodies whatever radiate caloric: the thermometer used in these experiments, therefore, emits rays of heat in the same manner as any other substance. When its temperature is in equilibrium with that of the surrounding bodies, it receives as much caloric as it parts with, and no change of temperature is produced. But when we introduce a body of a lower temperature, such as a piece of ice, which parts with less caloric than it receives, the consequence is, that its temperature is raised, whilst that of the surrounding bodies is proportionally lowered(31).

Emily. If, for instance, I was to bring a large piece of ice into this room, it would in time be melted, by absorbing caloric from the general radiation

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27. In what way do the mirrors increase the effect?
28. What is the principal fact proved by the mirrors?
29. What is remarked respecting the using a taper?
30. What would be the effect of substituting ice for the heated ball?
31. How is this explained?

which is going on throughout the room; and as it would contribute very little caloric in return for what it absorbed, the room would necessarily be cooled by it.

Mrs B. Just so; and as in consequence of the employment of the mirrors, a more considerable exchange of rays takes place between the ice and the thermometer, than between these and any of the surrounding bodies, the temperature of the thermometer must, therefore, be lowered more than that of any other adjacent object(32).

Caroline. I confess I do not perfectly understand your explanation.

Mrs B. This experiment is exactly similar to that made with the heated bullet: for, if we consider the thermometer to be the hot body and the ice to be the thermometer, the difficulty will cease; and let me tell you that ice has actually been used to ascertain the quantity of heat given out by warmer bodies, as the quantity of it which is melted will be proportioned to the heat which passes into it. In the present instance if the quantity of heat radiated by the bulb be represented by the number 20, and that from the ice by the number 10, it is evident that the former must lose twice as much as it receives, and its temperature must be reduced, without its being necessary to suppose that *cold* passes into it(33).

There is another view which may be taken of this fact, which may serve to explain it more familiarly. The effect of radiation is the same as that of slow communication by contact. Now suppose you were to place the bulb of the thermometer and the ice in contact with each other, what would be the result?

Emily. Why, to be sure, the thermometer would be reduced in temperature, as it must part with a portion of its heat to the colder body.

Mrs B. And this must as truly be the case when radiation is employed to equalize their temperature, the operation being merely facilitated by the employment of the mirrors(34).

Caroline. You have explained this in so satisfactory a manner, that I must confess I cannot help being convinced that cold has no real claim to the rank of a positive being.

Mrs B. Before I conclude the subject of radiation, I must observe to you, that different bodies (or rather surfaces) possess the power of radiating caloric in very different degrees(35).

Some curious experiments have been made by Mr Leslie on this subject. He ascertained that black surfaces radiate more, and polished metallic surfaces less than any others; the degree of radiation being proportioned to the greater or less brilliancy of the metallic surface(36).

Emily. Supposing these surfaces, of course, to be all of the same temperature?

Mrs B. Undoubtedly. I will now show you the very ingenious apparatus, by means of which he made these experiments. This cubical tin vessel, or canister, has each of its sides, externally, different; one is simply blackened over, the next very much tarnished by rubbing quicksilver upon it; the next scratched all over with sand paper, and the fourth highly polished.

This vessel, which is a cube of four inches, we shall fill with hot water, so that there can be no doubt that all its sides will be of the same tempera-

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32. In what way do the mirrors influence the result?
33. What is remarked respecting the ice being considered as the thermometer?
34. How is the fact explained by analogy?
35. What is said of the radiating power of different surfaces?
36. What gradation was observed in their radiation?

ture. Now let us place it in the focus of one of the mirrors, turning each of its sides towards it in succession. We shall begin with the black surface(37).

Caroline. It makes the thermometer which is in the focus of the other mirror show a considerably increased temperature. Let us turn the tarnished surface towards the mirror. The thermometer now falls a little; it follows, therefore, that this side does not emit or radiate so much caloric as the blackened side.

Emily. This is very surprising; for the sides are exactly of the same size, and must be of the same temperature. But let us try the scratched surface.

Mrs B. The thermometer indicates less heat; and with the polished surface still less. These two surfaces therefore radiate less and less.

Caroline. I think I have found out the reason of this.

Mrs B. I should be very happy to hear it; for it has not yet (to my knowledge) been accounted for.

Caroline. The water within the vessel gradually cools, and the thermometer shows this.

Mrs B. It is true that the water cools, but certainly to a much less extent than the thermometer indicates, as you will perceive if you now change the bright surface for the black one.

Caroline. I was evidently mistaken; for the thermometer again shows an increase of heat, now that the black surface fronts the mirror.

Mrs B. And yet the water in the vessel is still cooling, Caroline.

Emily. I am surprised that the bright surface should radiate the least caloric; for a metallic vessel filled with hot water, a silver tea-pot for instance, feels much hotter to the hand than one of black earthenware.

Mrs B. That has nothing to do with radiation, but is owing to the different power which various bodies possess for *conducting* caloric, a property which we have already examined(38). Although a metallic vessel feels warm to the hand, a polished vessel of this kind is known to preserve the heat of the liquid within, better than one of any other material; as it loses but little by radiation. It is for this reason that silver tea-pots make better tea than those of earthenware(39).

It has also been found that colour has a great influence upon radiation. Thus dark coloured cloths radiate more heat than those of a light colour, although they are alike in texture and material(40).

Emily. According to these experiments, white, or light-coloured dresses, in cold weather, should keep us warmer than black clothes, since the latter radiate so much more than the former.

Mrs B. And that is actually the case when we are in the shade; but in the sunshine, for a reason which you will presently learn, black would be the warmest(41).

Emily. This property, of different surfaces to radiate in different degrees, appears to me to be at variance with the equilibrium of caloric; since it would imply that those bodies which radiate most, must ultimately become coldest. Suppose, for example, that we were to vary the experiment, by using two metallic vessels full of boiling water, the one blackened, the other not; would not the black one cool the first?

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37. What kind of vessel may be used in these experiments?
38. Why does a metallic vessel feel hotter than one of earthenware?
39. Why is better tea made in silver than in earthen tea-pots?
40. What influence has colour on the radiation of a body?
41. What effect would this have upon dress?

the tin vessel of water, and the concave mirrors; the first radiates its own heat, the latter reflect the heat which they receive from other bodies(49).

Mrs B. We have yet much to say upon the subject of free caloric, as we have hitherto attended only to its nature, and the manner in which it is distributed among bodies. The effects which it produces upon them will afford ample matter for another conversation; as the notice of these effects will lead to the consideration of a number of collateral points which it is important you should understand.

CONVERSATION IV.

ON THE EFFECTS OF CALORIC.

Dilatation of Bodies. Pyrometer. Thermometer. Fixed Points. Air Thermometer. Differential Thermometer. Exceptions to the Law of Expansion. Fusion or Liquefaction.

Caroline. I had no idea whatever that the subject of heat would occupy one half of the space already passed; but it now seems to me that the part unexplored by us is more extensive than that over which we have travelled, as we have yet to consider the effects which heat produces upon bodies, and these must certainly be numerous.

Mrs B. A knowledge of all the causes and effects of a change of temperature in bodies, would be a complete knowledge of chemistry; as every change in the nature or the composition of any substance is produced or accompanied by a variation of its temperature(1). You will, therefore, at once see the importance of giving particular attention to the effects produced upon a body by the entrance of caloric into it. These effects are, 1st, *Expansion* or *Dilatation;* 2d, *Fusion* or *Liquefaction;* 3d, *Evaporation;* and 4th, *Ignition* or *Incandescense*(2).

One of the most remarkable properties of free caloric is its power of *expanding* or *dilating* bodies. This fluid is so extremely subtile, that it enters and pervades all bodies whatever, forces itself between their particles, and not only separates them, but frequently drives them to a considerable distance from each other. It is thus that caloric dilates or expands a body so as to make it occupy a greater space than it did before(3).

Emily. The effect it has on bodies, therefore, is directly contrary to that of the attraction of cohesion or aggregation; the one draws the particles together, the other drives them asunder.

Mrs B. Precisely. There is a continual struggle between the attraction of aggregation, and the expansive power of caloric(4); and from the action of these two opposite forces results those various forms of matter, in one of which all ponderable bodies are presented to us, viz. the *solid*, the *liquid*, and the *aeriform* or gaseous. Accordingly we find that most substances are capable of passing from one to another of these forms, merely in consequence of their receiving different quantities of caloric(5).

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49. What may serve as examples?
1. Why is the subject of heat of special importance?
2. In what order are its effects treated?
3. How is caloric supposed to operate in dilating bodies?
4. What power is opposed to calorific repulsion?
5. In how many forms are bodies presented to us?

Caroline. That is very curious; but I think I understand the reason of it. If a great quantity of caloric is added to a solid body, it introduces itself between the particles in such a manner as to overcome the attraction of cohesion in so great a degree, that the body, from a solid, is converted into a liquid(6).

Mrs B. This is the case whenever a body is fused or melted; but when you add caloric to a liquid, can you tell me what is the consequence?

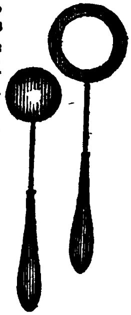
Caroline. The caloric forces itself in greater abundance between the particles of the fluid, and drives them to such a distance from each other, that their attraction of aggregation is wholly destroyed, and the liquid is transformed into vapour(7).

Mrs B. Very well; and this is precisely the case with boiling water, when it is converted into steam or vapour, and with all bodies that assume an *aeriform* state.

Emily. I do not well understand the word aeriform.

Mrs B. Any elastic fluid whatever, whether it be merely a vapour, or permanent gas, is called aeriform. Steam and the air of the atmosphere may serve as examples(8).

Emily. Are bodies in all these forms expanded by heat, or is it only when they are changed from one to the other that this dilatation takes place.



Mrs B. It is a general law that *bodies, in all their forms, are expanded by heat, and contracted by cold*(9). That this law operates on solid substances, I will show you by a simple but very decisive experiment. I have here a brass ball turned perfectly spherical, and a ring through which, as you see, it will just pass, when both are at the same temperature. I now dip the ball into boiling water, and it will no longer pass through the ring, but on heating the latter in the same way it passes as before. I again dip the ring into cold water, and it becomes too small to admit the ball through it.

Caroline. I knew that heat expanded bodies, but I had no idea that, with so small a degree of it, this effect could be rendered so very conspicuous(10).

Mrs B. By means of this other instrument (called a pyrometer) we may estimate, in the most exact manner, the dilatations of various solid substances by heat. The body we are now going to submit to trial is this small iron bar: I fix it to the apparatus, and then heat it by lighting the lamps beneath a metallic box through which it passes, and in which there is a portion of water. The fluid is made to boil, and heats the iron bar. When the bar expands, it increases in length as well as thickness, and, as one end communicates with these moveable levers, whilst the other end is fixed and immoveable, no sooner does it begin to dilate than it presses against the levers, and sets in motion the index, which points out the degrees of dilatation on the graduated segment(11).

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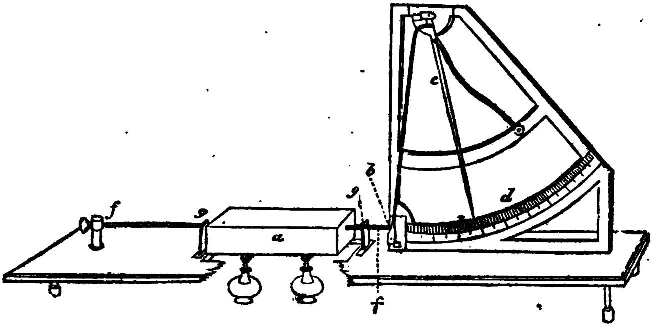
6. How does heat operate in converting a solid into a liquid?
7. How in producing the aeriform state?
8. What is meant by *aeriform?*
9. What is the general law respecting expansion?
10. How may the expansion of solids be shown?
11. Describe an instrument used for measuring the expansion of solids.

PYROMETER.



[The box *a* contains water to be boiled. *f f* is a metal rod to be heated, which passes through metallic studs *g g*, and this wire *a* is fixed firmly at one end, and at the other presses against the lever *b*, which operates on the index *c*, causing it to move along the graduated arc *d* to the distance of an inch, whilst the bar expands only 1-400 part of that distance.

The box *a* may be removed, and the lamps placed under the rod, when the expansion will be increased.]

Emily. This is, indeed, a very curious instrument; but I do not understand the use of the levers. Would it not be more simple, and answer the purpose equally well, if the bar, in dilating, pressed directly against the index, and put it in motion without the intervention of the levers?

Mrs B. The use of the levers is merely to multiply the motion, and, therefore, render the effect of the caloric more obvious; for if the index moved no more than the bar increased in length, its motion would scarcely be perceptible; but by means of the levers it moves in a much greater proportion, which therefore renders the variations far more conspicuous(12).

By submitting different bodies to the test of the pyrometer, it is found that they are far from dilating in the same proportion. Different metals expand in different degrees, and other kinds of solid bodies vary still more in this respect.

Caroline. I suppose that this difference of expansion results from the different force with which the particles attract each other.

Mrs B. You are perfectly correct; as caloric is the antagonist of cohesion or aggregation, it would necessarily follow that those bodies which possess the greatest tenacity would be less affected by a given quantity of heat, than those in which attraction is exerted with less force(13).

In conformity with this law, we shall find that fluids which possess but little aggregation, undergo a degree of expansion far exceeding that of solid bodies(14).

I have here two glass tubes, terminated at one end by large bulbs. We shall fill the bulbs, the one with spirit of wine, the other with water. I have coloured both liquids, in order that the effect may be more conspicuous. The spirit of wine, you see, dilates by the warmth of my hand as I hold the bulb.

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12. What is the use of the levers in this instrument?
13. Why do different solids expand differently?
14. How does this law affect the expansion of fluids?

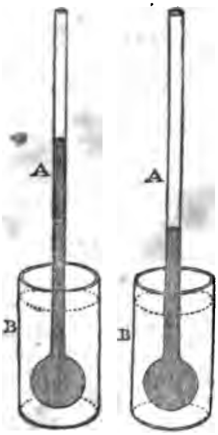
Emily. It certainly does, for I see it is rising into the tube. But water, it seems, is not so easily affected by heat; for scarcely any change is produced on it by the warmth of the hand.

Mrs B. True: we shall now plunge the bulbs into hot water, and you will see both liquids rise in the tubes; but the spirit of wine will ascend highest.

Caroline. How rapidly it expands! Now it has nearly reached the top of the tube, though the water has hardly begun to rise.

Emily. The water now begins to dilate. Are not these glass tubes, with liquids rising within them, very like thermometers(15)?

Mrs B. A thermometer is constructed exactly on the same principle, and is in fact a small bottle with a long narrow neck. Were you to fill such a bottle so that the contained fluid reached some way up the neck, you would find it rise in warm, and subside in cold weather, as in these tubes, which require only a scale to answer the purpose of thermometers: they would, however, be rather awkward in their dimensions(16). The tubes and bulbs of thermometers, though of various sizes, are, in general, much smaller than these. The tube too is closed, by melting the end of it so as to prevent the loss of the fluid, and to exclude the air. The fluid most generally used in thermometers, is mercury, commonly called quicksilver, the dilatations and contractions of which correspond more exactly to the additions and subtractions of caloric, than those of any other fluid(17).



A A tubes and bulbs.
B B vessels of warm water.

Caroline. Yet I have often seen coloured spirit of wine used in thermometers.

Mrs B. The expansions and contractions of that liquid are not quite so uniform as those of mercury; nor will it answer for temperatures much above the heat of summer, as the spirit, if more highly heated, would be converted into vapour. There are two cases, however, to which spirit of wine is particularly applicable: from its great expansibility it enables us to ascertain very slight variations of temperature; and its not being frozen by the most intense cold with which we are acquainted, renders it indispensable in measuring those lower degrees, where mercury and every other known fluid is converted into the solid state(18).

Emily. I have often seen it mentioned that the heat was so many degrees of Fahrenheit's scale, or of some other scale that was named. I do not understand how the difference of the scale can make any difference in the heat of the weather, or in that of any other thing.

Mrs B. The *scale* of a thermometer is merely a flat plate placed behind the tube, and marked with small divisions to show to what height the fluid rises(19). These divisions, like the weights and measures of different countries, are arbitrary. A pound or a foot in France is not the same with our

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15. By what experiment is the different expansion of liquids shown?
16. In what respect do such a tube and bulb resemble a *thermometer?*
17. What fluid is generally used in a thermometer?
18. Spirit of wine is sometimes used, what are its advantages and disadvantages?
19. What is meant by the *scale* of a thermometer?

pound or foot; so, different persons, or rather different countries, have adopted scales for thermometers, the degrees or divisions on which vary much from each other(20). All, however, proceed upon the same principle in obtaining what are called the fixed points. These fixed points are the temperature at which water freezes, and that at which it boils; as, under ordinary circumstances, these effects take place at the same degree every where(21).

In making a mercurial thermometer, after preparing the tube with a bulb at one end, the bulb and a part of the tube are filled with quicksilver, the quantity put in being such that it will stand above the bulb at the freezing, and not reach the top of the tube at the boiling point. It is then sealed *hermetically*, dipped into freezing water, and a mark made on the tube at the point to which the mercury sinks when in this situation: it is afterwards placed in boiling water, and a similar mark made at the point to which the mercury then rises. On putting it into boiling or freezing water at any other time, it will rise and fall to the same points. The tube thus prepared is fitted on a piece of metal or ivory, which is to be so divided as to form the scale. In doing this the boiling and freezing points are first transferred to the scale, whatever is to be the subsequent division(22).

Caroline. Then if thermometers were wanted to show these two points only, they would be alike in every country.

Mrs B. Yes, and it is the number of parts into which the spaces between these points are divided which constitutes the difference in the degrees. There are three different scales which you ought to know, as they are each in use, and two of them extensively; these are *Reaumur's*, the *Centigrade*, and *Fahrenheit's*(23). The former is divided into eighty parts or degrees, between the freezing and boiling points, so that by it water freezes at 0° and boils at 80°(24). The *centigrade* is now generally used in France, and is divided between the two fixed points, into one hundred parts; the freezing point is 0° and the boiling point 100°(25). In both these thermometers you count the degrees from the freezing point, the degrees below being called so many below freezing, or the term *minus* being used(26).

The thermometer used in this country and in England is Fahrenheit's. This is divided into 180° between the freezing and boiling points, and 32° of the same size are then laid off below the freezing point. From the last degree so laid off this scale begins; so that the freezing point is called 32°, and the boiling point 212°; thirty-two and eighty making that number(27).

Emily. The variety of scales must be very inconvenient, and, I should think, liable to occasion confusion in comparing our experiments and observations with those of the continent of Europe.

Mrs B. It is certainly inconvenient, as it gives some trouble, but need not create any confusion; it being easy to compare one scale with another, when we know the relative length of their divisions. In Reaumur's each degree is equal to 2¼ of Fahrenheit's; and five degrees of the centigrade are equal to nine of Fahrenheit. In comparing them, however, it must be recollected that the scale of the latter commences 32° below freezing(28). The thermometer which I now show you has two of these scales, Fahren-

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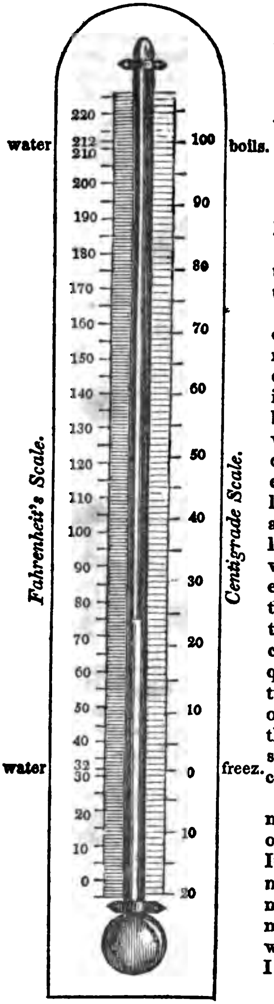
20. What has led to the adoption of different scales?
21. What are the *fixed points* in a thermometer?
22. State the general mode of procedure in making a thermometer.
23. What are the three scales denominated which are in use?
24. In what way is the scale of Reaumur divided?
25. How is the centigrade divided, and where is it used?
26. How are the degrees above and below freezing designated?
27. In what way are the divisions of Fahrenheit obtained?
28. In what way are these three scales compared?

heit's and the centigrade, one on each side of the tube. (See the word thermometer in the glossary).

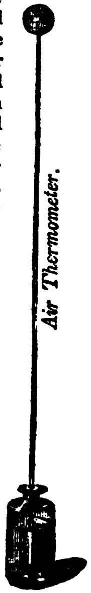


Caroline. The centigrade seems to me the most reasonable division; and I cannot imagine why the freezing point is called 32°, or what advantage is derived from it.

Mrs B. There really is no advantage in it; and it originated in a mistaken opinion of the instrument-maker, Fahrenheit, who first constructed these thermometers. He mixed snow and salt together and produced by that means a degree of cold which he concluded was the greatest possible, and therefore made his scale begin from that point(29).

Emily. Are spirit of wine and mercury the only liquids used in the construction of thermometers?

Mrs B. They are the only liquids in general use for this purpose; but for experiments in which a very quick and delicate test of the changes of temperature is required, air is sometimes employed(30). The bulb of an air thermometer is filled with common air only, and the tube or stem, which should be sixteen or eighteen inches long, has its end left open. If this end be inverted in a cup containing some coloured liquid, and the bulb grasped in the warm hand, the air within being expanded, will be seen bubbling up through the liquid. On withdrawing the hand, the air will contract by cooling, and in consequence the liquid will gradually ascend in the tube, its altitude always depending on the expansion and contraction of the air. The amount of this expansion and contraction may be indicated by a scale(31).


Air Thermometer.

Such was the first kind of thermometer made, and it was the invention of Sanctorio, an Italian philosopher. It is found very useful for detecting minute changes of temperature in many chemical experiments. If I merely breathe on the bulb you will see that the liquid sinks, and if I then blow on it that it rises(32).

Caroline. This instrument serves

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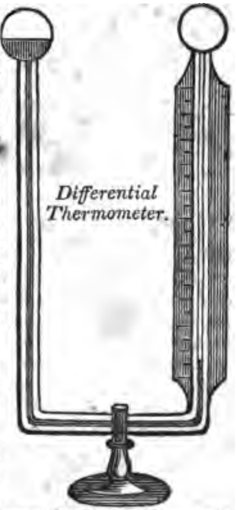
29. What led Fahrenheit to the adoption of his zero?
30. What forms the most delicate thermometer?
31. Describe the construction and operation of the air thermometer.
32. What is said in proof of its great sensibility?

also to show the expansion of air by heat, and that in this respect it greatly exceeds either solids or liquids.

Mrs B. You have anticipated my calling your attention to this fact, as it completes the evidence of the expansion of bodies in all their forms. That the dilatation of air should be greater than that of solids or liquids follows of necessity, from the circumstance of there being in it no attraction of cohesion to overcome(33).



Differential Thermometer.

Before dismissing the air thermometer I will show you one of a very peculiar construction, which was contrived by Mr Leslie to use in his experiments on the radiation of heat from different surfaces. It is called the *differential thermometer*, and consists of a glass tube nearly in the form of the letter U, with a bulb at each termination. Each of these bulbs contains air, and there is some coloured liquid in the tube which moves when the air in only one of the bulbs is dilated or contracted, but remains stationary whenever they are both exposed to the same temperature. If, therefore, you take the instrument from one room to another of a different temperature, as the air in each bulb will be equally expanded or contracted, the liquid will not show any evidence of the change(34).

Emily. This seems rather a strange kind of thermometer which undergoes no change in being removed from a hot into a cold place.

Mrs B. The name of *differential* was given to it, because it shows the difference of temperature in the two bulbs. It was on this account peculiarly adapted to Mr Leslie's experiments, when one bulb was placed in the focus of the mirror; for it would remain unaffected by every change of temperature in the room, but indicate any variation which took place in the focus by radiation(35).

Emily. But do common thermometers indicate the exact quantity of caloric contained either in the atmosphere, or in any body with which they are in contact?

Mrs B. No: first, because there are modifications of caloric which do not affect the thermometer; it is in fact only the *free* caloric which does affect it; and, secondly, because the temperature of a body, as indicated by the thermometer, is only relative. When, for instance, the thermometer remains stationary at the freezing point, we know that the atmosphere, (or medium in which it is placed, whatever it may be), is as cold as freezing water; and when it stands at the boiling point, we know that this medium is as hot as boiling water; but we do not know the positive quantity of heat contained either in freezing or boiling water, any more than we know the real extremes of heat and cold; and consequently we cannot determine that of the body in which the thermometer is placed(36).

Caroline. I do not quite understand this explanation.

Mrs B. Let us compare a thermometer to a well, in which the water rises to different heights, according as it is more or less abundantly supplied

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33. What reason exists that air should dilate more than other bodies?
34. Describe the differential thermometer.
35. Why is it so called, and to what particular use was it applied?
36. Does a thermometer indicate the quantity of caloric in a body?

by the spring which feeds it. If the depth of the well is unfathomable, it must be impossible to know the absolute quantity of water it contains; yet we can with the greatest accuracy measure the number of feet the water has risen or fallen in the well at any time, and consequently know the precise quantity of its increase or diminution, without having the least knowledge of the whole quantity of water it contains(37).

Caroline. Now I comprehend it very well: nothing appears to me to explain a thing so clearly as a comparison.

Emily. But will thermometers bear any degree of heat?

Mrs B. No: for if the temperature were much above the highest degree marked on the scale of the thermometer, the mercury, by its expansion, would burst the tube: and no thermometer can, on any account, be applied to temperatures higher than the boiling point of the liquid used in its construction; for, on the liquid beginning to boil, the steam would burst the tube(38).

Caroline. True, this point must limit the degree of heat which can be measured by the thermometer; but how then can we ascertain the high temperature of our fires, and of furnaces?

Mrs B. There is yet no accurate instrument known for effecting this, although several have been devised. That which has been most depended upon is a pyrometer invented by Wedgwood. Clay possesses the property of contracting in the fire to a very considerable extent, and in a degree which is proportioned to the heat to which it has been exposed(39). To take advantage of this property, Mr Wedgwood used a particular kind of clay, which he baked so as to expel the moisture contained in it. Pieces of this, half an inch in diameter, were placed in an earthen-ware, glass-house, or other furnace, and when taken out they were measured by a particular kind of gauge, to ascertain how much they had diminished in bulk, and from this diminution the degree of heat was estimated(40).

Emily. And what has been the difficulty in the use of this means for the purpose intended? I can see none, if the clay shrinks in proportion to the heat.

Mrs B. Besides some other objections, it has been found that the clay will decrease in bulk by a lengthened exposure to the same temperature, and that its indications were not therefore to be depended upon(41). The observations made by it, however, are useful, although not considered as perfectly accurate.

Caroline. It seems that in this case we have to unlearn what you have just been taking so much trouble to teach us, that all bodies are expanded by heat; for you tell us that it contracts the clay(42).

Mrs B. There is certainly much difficulty on this point, arising undoubtedly from the imperfection of our knowledge. Whether in the instance we are considering, the clay affords a real, or only an apparent exception to a very general law, is still a question. When it is first put into the fire it is a porous, spongy mass; when it comes out, it is close and compact. Although it has not undergone fusion, still the fire has had the effect of so arranging its particles as to diminish the quantity of pore, and consequently, to lessen the dimensions of the mass. After the piece has been taken from

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37. How is this illustrated by comparison?
38. What limits the temperature measured?
39. What particular property is possessed by clay?
40. In what way did Mr Wedgwood employ it?
41. What circumstance rendered it inaccurate?
42. What does the contraction of the clay seem to contradict?

the fire, however, and allowed to cool, it will then be found, like other bodies, to expand by heat and contract by cold(43).

Caroline. If there are no other exceptions to the law than this, I shall feel inclined to be satisfied; but if there are many such, I scarcely think it ought to be called a law.

Mrs B. I know of but one other, which, to a certain extent, is a real exception, and one which we shall find to be wisely ordered, for a most beneficent purpose in the economy of nature. The substance in which it takes place is water(44).

Emily. But did we not see that water expanded by heat, and contracted by cold, as well as spirit of wine, although in a less degree?

Mrs B. You are perfectly correct: as water is cooled, it continues to contract until it arrives at 40°, which you know is 8° above the freezing point; but after this it absolutely expands until it descends to 32°, when it begins to freeze(45).

Caroline. I should like to know the cause of this.

Mrs B. And I should be pleased if I could tell it to you. The most plausible explanation of it that I have met with, is founded on the known fact that water when it freezes expands considerably; ice being less dense than water. That arrangement of the particles upon which the increased bulk depends, must take place whilst they are in a fluid state, and this it has been supposed commences at 40° and is completed at 32°(46).

Although the cause may be obscure, the beneficial effect of the circumstance we are considering is evident. This property of water, in conjunction with its previous contraction, prevents the freezing of deep lakes, even in very cold climates, and causes our rivers and other comparatively shallow waters to freeze at the surface only(47).

Can you tell me, Emily, what will be the effect upon a body of water, when the atmosphere becomes so cold as to be below the freezing point?

Emily. I think so. The cold air will deprive the water of a portion of its caloric at the surface, and this cooled water being rendered more dense, will descend, and expose a new stratum to the air; and unless the weather should change, this process will continue until all the water is brought to the temperature of the air.

Mrs B. In the former part of your explanation, you are right; in the latter, wrong. The cooled stratum of water will descend until the whole is reduced to 40°; but after this, as it cools, it expands, and therefore the internal motion, occasioned by the increased specific gravity of the condensed particles, ceases; for when the water at the surface no longer condenses, it will no longer descend, and leave a fresh portion exposed to the atmosphere. The same surface, therefore, will be further deprived of its caloric, and will soon be brought down to the freezing point. When it becomes ice, this being a bad conductor of heat, preserves the water beneath a long time from being affected by the external cold(48).

In very deep lakes the whole length of winter is insufficient to produce this effect; and in rivers, and all other waters, when the surface is frozen, that below is still above the freezing point, and may be at 40 degrees(49).

Caroline. And the sea also does not freeze, I suppose, because its depth

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43. What remarks are made respecting this contraction?
44. What other body furnishes an exception to the law of expansion?
45. Under what circumstances does this exception exist?
46. To what cause is it attributed?
47. What benefit results from it?
48. What is the process of cooling in deep water?
49. What is the consequence in very deep lakes and in rivers?

is so great, that the frost never lasts long enough to bring down the temperature of such a vast body of water to 40 degrees?

Mrs B. That is one reason why the sea, as a large mass of water, does not freeze. But, independently of this, salt water does not freeze till it is cooled much below 32 degrees. Salt water is also an exception to the law of condensation, obeyed by fresh water, as it continues to condense even many degrees below the freezing point. When the caloric of fresh water, therefore, is imprisoned by the ice on its surface, the ocean still continues throwing off heat into the atmosphere, which is a most signal dispensation of Providence to moderate the intensity of the cold in winter(50).

This, as well as some other points connected with changes of temperature in several of the operations of nature, you will more perfectly understand after having attended to combined caloric, which will be the subject of our next conversation. Do you recollect our second division of the effects of caloric?

Emily. Yes, very well; it was *fusion* or *liquefaction*(51), which we know takes place in a great number of bodies; but I think we shall find more exceptions to this than to the law of expansion.

Mrs B. Perhaps you may find more apparent, but no real exceptions. The property of repulsion is manifestly owing to caloric; and as it is easy, within certain limits, to increase or diminish the quantity of this principle in any substance, it follows that the forms of bodies may be made to vary at pleasure; that is, by a sufficiently intense heat every solid may be converted into a fluid, and every fluid into the aeriform state(52). This inference is so far justified by experience, that it may safely be considered as a general law. The temperature at which liquefaction takes place, is called the melting or fusing point; and that at which liquids become solids, the point of congelation(53). For each individual substance these points are the same, as 32° is the point of fusion and of congelation for water; but in the fusing point of different substances, as of ice and of iron, there is an immense variation(54).

Caroline. It seems to me that the distinction of solid and fluid is altogether accidental, as it depends upon the temperature to which a body is exposed.

Mrs B. It is undoubtedly so. Were the medium temperature of our globe below 32°, we should class water among solids, and speak of its fusion as we now do of that of wax or tallow. Abstracting the operation of caloric, therefore, the natural state of all bodies would be the solid(55).

Emily. All then that is necessary to convert a solid into a fluid is to destroy the attraction of cohesion among its particles.

Mrs B. Not exactly so. When you reduce a solid to an impalpable powder you destroy its attraction of cohesion, but you do not thereby form a fluid. In a fluid the attraction of cohesion is not destroyed, but only modified by the agency of caloric. Drops of water and of other liquids cohere; two small drops of water, or globules of mercury, if brought into contact, will run into one, manifesting a considerable force of attraction(56).

Caroline. There appears to me much difficulty in conceiving how a body can be a fluid whilst its particles attract each other, as it is upon this pro-

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50. Does salt water obey the same law?
51. After expansion, what is the next general effect of heat?
52. What remarks are made on the liquefaction of solids?
53. What are the two points called at which the change occurs?
54. What is said respecting the fusing point of different bodies?
55. What is said of the natural state of bodies?
56. What respecting attraction in fluids?

perty that solidity depends; yet it is evident that in these particles attraction is not destroyed.

Mrs B. Fluidity has been considered as depending upon the equable attraction of the particles in whatever position they may be placed. Solids are supposed to be such because the particles of which they are composed attract each other with greater force in certain directions than they do in others, and a corresponding power, therefore, will be necessary to alter their positions; but if, by introducing caloric, you can equalize the attraction so that it remains the same in every direction, there then being no resistance from attraction, the particles will move among themselves with perfect facility, and it is this which constitutes fluidity(57).

Caroline. The reasoning appears to me to be satisfactory, and yet there is a something in the action of these particles which seems to make it very difficult to reason about them; for although they must exist, it is not as sensible objects that they do so, but as mere ideas of the mind.

Emily. I have been looking for an explanation of the exceptions to this law, which seem to me to present themselves in crowds. Wood, linen, paper, coal, and many other things undergo combustion without showing the least tendency to fusion(58).

Mrs B. Your enumeration of *apparent* exceptions is very good, and it is perfectly natural that they should present themselves to you as really such; but all the various articles of which these bodies are composed, are in other combinations, frequently found in the fluid state(59). Such substances as you have mentioned do not become fluid when subjected to the action of heat, because they are decomposed at a temperature below that which is requisite for their fusion. In proof of this, chemists have effected the fusion of some of them, by the adoption of such means as prevented their decomposition(60).

Caroline. There appears to be something more than mere decomposition in the combustion of these bodies. They not only escape from being converted into fluids, but actually go out of existence. From wood, for example, a little smoke flies off, and some light ashes remain behind, but the larger part of it, both in weight and bulk, vanishes entirely(61).

Mrs B. You will soon learn that not an atom of it is lost; that although the chemical union is dissolved, the matter remains, possessed of all its mechanical attributes. The solid substance has been converted by heat into invisible, elastic fluids, but in this there is no approach towards annihilation. We may alter the forms of bodies, but we have no more power to destroy a single particle of matter than we have to create it. Whilst reason sanctions, chemistry most beautifully exemplifies the universality of this truth(62).

Heat not only liquefies, but may be rendered sufficiently intense to convert most bodies into vapour, and we believe that in their nature, all are susceptible of the same change, although we have not yet, in every instance, succeeded in effecting it(63). Evaporation, you know, is the third general effect of free caloric. This, with ignition, we will talk about to-morrow; and however interesting you may have found those effects of heat which we have already examined, that which we have next to consider, will, I think, be still more so.

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57. How is the state of fluidity explained?
58. What apparent exceptions are there to the fusibility of bodies?
59. What is said respecting such bodies in other combinations?
60. Why do not wood, coal, and other such bodies liquefy?
61. What remark does Caroline make?
62. Can any portion of matter be annihilated?
63. What is believed respecting the evaporation of all bodies?

CONVERSATION V.

EFFECTS OF CALORIC CONTINUED.

Fixed and volatile Bodies. Evaporation and Vaporization. Boiling. Influence of Atmospheric Pressure. Steam. Solution and Saturation. Wollaston's Thermometer. Water frozen by vaporizing Ether. Distillation. Ignition.

Caroline. I am quite anxious, Mrs B., to enter upon the subject of our morning's lesson; for although I know that water, and milk, and other liquids may be evaporated by heat, I have never had an idea that this could take place with bricks and stones. I am now, however, prepared to believe almost any thing excepting my senses; but I confess that I should like much to see a block of marble boiled away.

Mrs B. Your reason, my dear child, was given to guide your senses, by enabling you to treasure up, and compare with each other, the facts which you observe, and thence to deduce results with respect to what is unseen, equally certain and satisfactory with those which are actually the objects of sense. Bricks and stones may be fused in a common smith's forge, and analogy convinces us that it is only the limited means which we possess that prevents us from converting them into vapour(1). Those substances which we cannot convert into vapour, are called *fixed*, whilst those which are evaporable are called *volatile*(2). The high temperature which the improvements in science have enabled the chemist to command, has greatly reduced the catalogue of fixed bodies, and it is not improbable that those which remain are destined ere long to yield practical evidence of the truth of the general law(3).

Caroline. As it is the attraction of cohesion which keeps bodies together in the mass, and as heat appears to be the agent of repulsion, it is evident that it only requires an excess of caloric completely to counteract this attraction, however powerful it may be(4).

Emily. I can understand very well how caloric may convert liquids into vapour; but still there seems to be other means of effecting this, as we know that water dries away not only at the common temperature of the atmosphere, but that even in cold frosty weather, clothes which are hung out will still become dry, although they may freeze. It would seem, therefore, that cold may evaporate bodies as really, if not as rapidly, as heat; or, as cold is merely a negative state, perhaps I ought rather to say that air as well as caloric will convert bodies into vapour(5).

Mrs B. You will find after a little inquiry, that caloric is still the agent, whether bodies are converted into vapour at natural or at artificial temperatures, and that the processes of *evaporation* and *vaporization* bear a strong analogy to each other(6). They, however, are very properly distinguished by different names; and though we do not always restrict ourselves to the correct employment of these terms, yet the precision of our ideas would be promoted by greater care in this particular.

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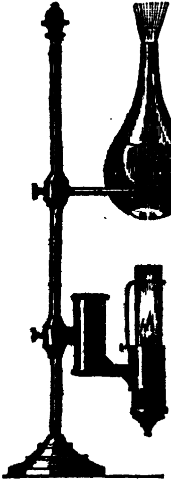
1. Why cannot bricks and stones be converted into vapour?
2. How are bodies classed in respect to this effect of heat?
3. What is rendered probable respecting fixed bodies?
4. What reason is urged in support of this opinion?
5. What remark is made on evaporation without heat?
6. What is the reply to the objection made?

By *evaporation* we mean the conversion of bodies into vapour at common temperatures, and by *vaporization* the rapid production of vapour by ebullition(7); the only assignable difference between them is, that the former takes place quietly, the latter with the appearance which we denominate boiling(8). In every case, however, all other circumstances being alike, we shall find that the rapidity of the process is precisely proportioned to the temperature. We cannot enter fully into this part of our subject until you know something of combined caloric; still there are some facts and experiments connected with it, which we shall presently attend to, as they will serve to illustrate the truth, that vapour is not produced without heat, and consequently that caloric is the cause of this change of form.

Caroline. I do not exactly perceive why evaporation should proceed so quietly as to be invisible during the process, whilst boiling is accompanied with so much agitation, if the cause producing each is precisely the same.

Mrs B. The essential difference between the two is, that in evaporation the vapour rises from the surface, only, of the liquid, whilst in boiling it is produced at the bottom of it, where the heat is applied, and in passing up through the liquid causes that agitation which we call boiling(9). That evaporation is proportioned to the extent of the surface of a fluid is proved by the fact, that although the depth of the water in a vessel may be increased, its loss by evaporation will not be affected thereby; whilst, if you place it in another vessel in which the surface of the water is doubled, the evaporation will be doubled also(10). In boiling, on the contrary, the vaporization is proportioned to the intensity of the fire, and the extent of that part of the vessel which is exposed to its action(11).

Emily. Then the difference seems to be that in evaporation the heat is in the air above the liquid, and in boiling it is in the fire below it; and in this case, it seems to me, that were we to apply the fire over the water, it ought to evaporate only, and not to boil.



Mrs B. Your reasoning is good, and your conjecture just. It is, however, as you know, very difficult to heat water from above, on account of liquids being such bad conductors of heat; but were you to bring it to the boiling point, the consequence would be only a rapid evaporation, without any commotion(12).

We will boil some water in this Florence flask, in order that you may be well acquainted with the process of ebullition: you will then see, through the glass, that the vapour rises in bubbles from the bottom. We shall make it boil by means of a lamp, which is more convenient for this purpose than the chimney fire.

Emily. I see some small bubbles ascend, and a great many appear all over the inside of the flask; does the water begin to boil already?

Mrs B. No: what you now see are bubbles of air, which were either dissolved in the water, or attached

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7. What is intended by the terms *evaporation* and *vaporization?*
8. What is the sensible difference between them?
9. What produces the agitation in boiling?
10. To what is *evaporation* proportioned and how is this shown?
11. To what is *vaporization* proportioned?
12. What would be the effect of applying heat above a fluid?

cooled and partially condensed, the minute drops of water, which are *mixed* with the air, become visible; but then again as they pass into the room, they acquire a fresh portion of caloric from the atmosphere, are again dissolved, and therefore no longer seen(29).

Caroline. Solution then is a mode of destroying the attraction of aggregation(30).

Mrs B. Undoubtedly. The two principal solvent fluids are *water* and *caloric*(31). You may have observed that if you dissolve salt in water it becomes totally invisible, and the water remains clear and transparent as before; yet though the union of these two bodies appears so perfect, it is not produced by any chemical combination which permanently alters the nature of either of them; for if you were to separate them by evaporating the water, you would find the salt in the same state as before. You are not, however, to conclude that there is in this case no chemical union at all, but merely that it is one which is easily destroyed(32).

Emily. I suppose that water is a solvent for solid bodies, and caloric for liquids?

Mrs B. Liquids, of course, can only be converted into vapour by caloric; but the solvent power of this agent is not at all confined to that class of bodies. A great variety of solid substances are dissolved by heat; thus metals, which are insoluble in water, can be dissolved by intense heat, being first fused or converted into a liquid, and then rarefied into an invisible vapour. Many bodies yield to either of these solvents(33).

Caroline. And that, no doubt, is the reason why hot water will dissolve most bodies much better than cold water.

Mrs B. It is so. Caloric may, indeed, be considered as having in every instance, some share in the solution of a body by water, since water, however low its temperature may be, always contains more or less caloric(34).

Emily. Then, perhaps, water owes its solvent power merely to the caloric contained in it.

Mrs B. That, probably, would be carrying the speculation too far. I should rather think that water and caloric unite their efforts to dissolve a body, and that the difficulty or facility of effecting this, depends both on the degree of attraction, or aggregation, to be overcome, and on the arrangement of the particles which are more or less disposed to be divided and penetrated by the solvent(35).

Emily. But have not all liquids the same solvent power as water?

Mrs B. The solvent power of other liquids varies according to their nature, and that of the substances submitted to their action. Some of them, particularly the acids, dissolve the metals, and in so doing are themselves, in many cases, decomposed. A great variety of new substances is thus formed(36); but these more complicated operations we must consider in another place, and confine our attention, at present, to the solutions by water and caloric.

Caroline. But there is a variety of substances which, when dissolved in water, make it thick and muddy, and destroy its transparency.

Mrs B. In this case, it is not a solution, but simply a mixture. I shall

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29. How does this exemplify the difference between *solution* and *mixture?*
30. What does solution destroy?
31. What are the principal solvents?
32. What is remarked on a solution of salt in water?
33. What general remarks are made upon water and heat as solvents?
34. Does caloric appear to be concerned in solution generally?
35. What appears to be the joint action of water and caloric?
36. What is said of other solvents?

show you the difference between a solution and a mixture, by putting some common salt into one glass of water, and some powder of chalk into another. Both these substances are white, but their effect on the water will be very different.

Caroline. Very different, indeed: the salt entirely disappears, and leaves the water transparent, whilst the chalk changes it into an opake liquid like milk.

Mrs B. One character of a solution is transparency. It need not be colourless, as there are solutions of almost every variety of colour, but they are all transparent(37). A powder, however fine it may be, will render a fluid opake, if it remains undissolved, and will, most commonly, be *precipitated*, or fall to the bottom, if the fluid be allowed to remain at rest. This is never the case with a solution, although the specific gravity of the article dissolved be much greater than that of the fluid with which it has combined(38).

Caroline. A portion of salt which I have added to the water remains undissolved, although I have continued to stir it for a long time; yet at first it dissolved very quickly.

Mrs B. There is a certain quantity of a substance which its solvent can take up: when this quantity is dissolved, the point of *saturation* is attained, and we have what is denominated a *saturated solution.* In the present instance the water is saturated, and has no more power to dissolve an additional portion of salt than of sand(39).

Emily. Is not the air a solvent for water? In a windy day water dries away with much greater rapidity than in still weather.

Mrs B. It was formerly supposed, from the case you have stated, that water was dissolved by the air; but it appears from more accurate observations, that the solvent power of the atmosphere depends solely upon the caloric contained in it. The motion of the air removes that which has been dissolved, which otherwise would prevent all further solution. You will presently see that by removing the atmosphere, the quantity of water dissolved will be increased(40).

Do you recollect upon what principle the barometer is used for measuring the altitude of mountains, or the height to which a balloon ascends?

Caroline. Perfectly well. As you ascend the quantity of air above you decreases, and it must consequently become less and less dense, and press with decreasing force. The mercury in the barometer, therefore, descends in proportion to the elevation of the place to which it is taken(41). Now let me tell you why you made that inquiry: it was to show that water must boil at a lower temperature in such situations; was it not(42)?

Mrs B. You have guessed, or rather judged right, and the late Rev. Mr Wollaston showed how, upon this principle, the thermometer might be substituted for the barometer in measuring heights. He made a thermometer in which every degree on Fahrenheit's scale was divided into one thousand parts; and such was its extreme sensibility that it evinced a difference in the heat of boiling water in a vessel placed first on the floor, and

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37. How may the difference between mixture and solution be shown, and what is a uniform character of solution?
38. What further difference is noticed?
39. What are *saturation*, and a *saturated solution?*
40. How is water dissolved in the atmosphere?
41. How does the barometer operate in measuring altitudes?
42. How must water be affected in elevated situations?

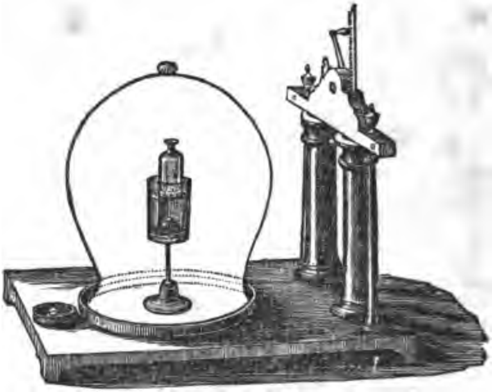
afterwards upon a table. The most perfect and delicate barometer falls very far short of this(43).

Emily. I am glad to see the air pump upon the table, and the bottle of ether, which is to boil over a fire as cold as ice. After seeing ice cause water to boil, I shall not be surprised to see it produce the same effect upon ether, which is so much more volatile.

Mrs B. You will find them to be very different operations: in the former experiment the ice produced the boiling; in the present you will find the boiling produce the ice. Observe how suddenly the ether in this phial will be converted into vapour, by means of the air pump. See with what rapidity the bubbles will ascend, as I take off the pressure of the atmosphere. To show this I open the vial, place it under a receiver, and exhaust the air(44).

Caroline. It positively boils: how singular to see a liquid boil without heat!

Air Pump with Receiver and Apparatus for freezing Water.



Mrs B. Now I will place the phial of ether in this small cylindrical glass, which it so nearly fits as to leave only a small space between them, which I fill with water; and in this state I put it again under the receiver. You will observe, as I exhaust the air from it, that whilst the ether boils, the water freezes(45).

Caroline. It is indeed wonderful to see water freeze in contact with a boiling fluid!

Emily. I am at a loss to conceive how the ether can pass to the state of vapour, without an addition of caloric. Does it not contain more caloric in a state of vapour, than as a liquid?

Mrs B. It certainly does; for though it is the pressure of the atmosphere which keeps it in the state of a liquid, it cannot pass into the aeriform state without absorbing a quantity of caloric.

Emily. You have therefore, two difficulties to explain, Mrs B. First, whence the ether obtains the caloric necessary to convert it into vapour, when it is relieved from the pressure of the atmosphere; and, secondly, what is the reason that the water, in which the bottle of ether stands, is frozen?

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43. How did the Rev. Mr Wollaston exemplify this?
44. How may ether be made to boil by means of the air pump?
45. By what arrangement may water be frozen?

Caroline. Now I think I can answer both these questions, and so kill two birds with one stone. The ether obtains the addition of caloric required from the water in the glass; and the loss of caloric which the latter sustains, is the occasion of its freezing(46).

Emily. This I understand now very well; but if the water freezes in consequence of yielding its caloric to the ether, the equilibrium of heat must, in this case, be totally destroyed. Yet we have been told that the exchange of caloric between two bodies of equal temperature, is always equal; how, then, is it that the water, which was originally of the same temperature as the ether, gives out caloric to it, till the water is frozen and the ether made to boil?

Mrs B. I had anticipated that you would make these objections, but can assure you that the equilibrium of temperature is not destroyed; for were we to place one thermometer in the ether, and another in the water, and observe them during the experiment, we should find that they would descend equally; that both thermometers would indicate the same temperature, though one of them were in a boiling, the other in a freezing liquid(47).

Emily. The ether, then, becomes colder as it boils. This is so contrary to common experience, that I confess it astonishes me exceedingly.

Caroline. It is, indeed, a most extraordinary circumstance. But pray how do you account for it?

Mrs B. I cannot satisfy your curiosity at present, but must defer the explanation, with that of some other facts which we have partially noticed, until our conversation on combined caloric, or latent heat. The fact, however, of the intense cold produced by the evaporation of ether, will be rendered sensible by your allowing a drop or two to fall upon the back of your hand, from the bottle.

Caroline. Oh, how cold! and it is scarcely on before it is dry. I had not the most remote idea of the intensity of the sensation it would produce, as the bottle appeared not to be colder than the other articles in the room(48).

Mrs B. The cold is entirely the effect of the evaporation, and all evaporation is attended with a similar result. The intensity of the cold must of course be proportionate to the rapidity of the process; and therefore the most volatile fluid must produce the most striking effect(49).

Emily. Pray, Mrs B., what would become of the water in the ocean, and in our rivers, were the pressure of the atmosphere removed? It appears to me that it would all boil away; at all events this must be the case in tropical climates, where the heat is generally above 88°.

Mrs B. This use of the atmosphere affords another example of the providential care and wisdom of the Creator, and ought to operate as an additional incentive to the study of his works, in which we find so many important purposes effected by means the most simple. The atmosphere is necessary to sustain life, and it obviously answers numerous other valuable ends; but who, unless informed by science, would ever have dreamt that the existence of the ocean, and of every stream of water, depends upon its pressure? It is a fact, however, that, in every climate, but for this force, the whole of them would be soon converted into watery vapour, and form an aqueous atmosphere, surrounding the earth, but answering none of those purposes which are requisite to render it habitable(50).

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46. Upon what principle does this depend?
47. What will be the respective temperatures of the ice and ether?
48. What sensation will be produced if ether be dropped on the hand?
49. From what cause does the cold produced arise?
50. What would become of the waters, were atmospheric pressure removed?

Caroline. The little that we have learned, Mrs B., by your persevering kindness, would be a rich reward for the labour of years; and I am sure that the delight which it has already afforded us will be an effectual motive to perseverance. We are indeed most grateful to you for directing us to sources of enjoyment so far superior to what is usually denominated pleasure.

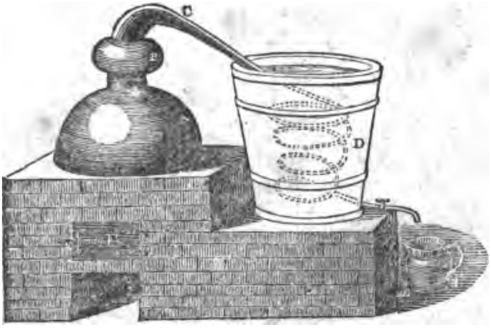
Mrs B. Before dismissing the subject of vaporization, there is a chemical process, the nature and object of which you should fully understand, and that is *distillation.* The principal object of this process is to separate and collect the more volatile of two fluids which may be mixed together. This operation is founded upon the difference in the boiling points of different fluids, in consequence of which, when heat is applied to them in their mixed state, one of them will evaporate at a lower temperature than the other(51).

Caroline. I have seen them distilling spirits, which I believe was obtained from rye, and have understood that it can be procured from many other articles.

Mrs B. All the liquors called vinous, such as the various kinds of wine, beer, cider, &c. contain a spirituous liquid called *alcohol*, or spirits of wine, but mixed with water, and other matters(52). When heated, the alcohol first rises in vapour, and were this evaporation to be carried on in an open vessel, the vapour would fly off and be lost. The apparatus usually employed is called an alembic, or still, and is generally made of copper. I will show you a drawing of one presently; but a common tea kettle will afford you some idea of its nature. Suppose that the liquid to be distilled was put into one of these vessels, with the lid so secured that steam could not escape, excepting through the spout, that a long tube was fastened to the spout, and this tube made to pass through a vessel of cold water; any vapour which passed into the tube would be condensed, assume the liquid form, and fall in drops out of the tube(53).

Emily. And if we were to put a vinous liquor into such a kettle, and heat it, the spirit would rise first, and leave the watery part behind.

Common Alembic, or Still for Spirits.



Mrs B. Yes; but it would, in the first instance, be accompanied by a considerable portion of the water, from which it must be ~~separated by redis-~~

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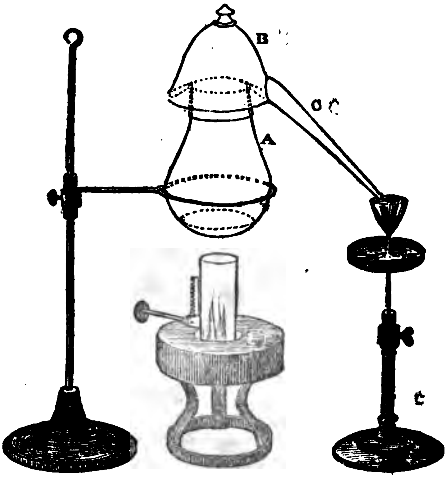
51. What is the object of distillation, and upon what does it depend?
52. What is contained in *vinous* liquors of every description?
53. What is an alembic, or still, and what does it resemble?
45. By wh

tillation or *rectification*, as it is called(54). This is a drawing of a still. A, is the body of the still, which is to be enclosed in a furnace. B, the head, or capital. C, the beak or spout. D, the worm, which is a long metal tube enclosed in the refrigerator, which is a tub or cistern kept full of cold water. E, a vessel for receiving the spirits which have been condensed in passing through the worm(55). It is by an apparatus of this description that the various kinds of spirituous liquors are obtained, such as brandy, rum, gin, whiskey, and a variety of others.

Caroline. As spirit is converted into vapour at a temperature so far below that of water, is it not possible, by regulating the heat, to obtain the spirit pure at once without rectification?

Mrs B. By no means. When two fluids of different volatility are combined together, they modify each other's properties. When the more volatile of the two is driven off, it will, in consequence of the force of the affinity by which they are united, carry with it a certain portion of that which is less so. This is the case even with solids, there being very few with which water combines which are not, in part, converted into vapour, when the water is driven off by heat(56).

Glass Alembic for Distillation.



[A, body of the Alembic. B, the head. C, the beak for conducting the condensed fluid into the glass.]

In distilling in the small way, an operation which we shall have frequent occasion to perform, the chemist sometimes uses an alembic of glass, such as I now have over the lamp. By keeping the head and beak cool, the vapour which rises is condensed, and drops out in the liquid form. Such an apparatus is useful on account of the smallness of the quantity which may be operated upon by it. The progress of the experiment may be seen, and

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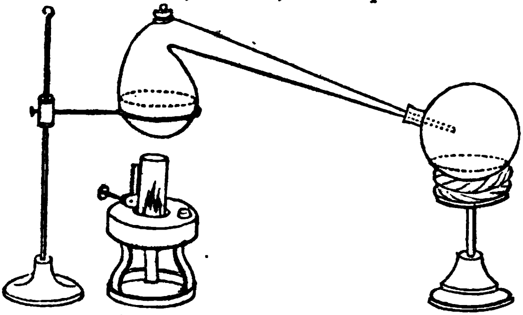
54. What is rectification, and why is it necessary?
55. Describe the common still and its refrigerator.
56. Why may not pure spirit be at once obtained?

substances which would destroy the metals, are thus prepared or employed(57).

What is called a *retort* is the kind of still most commonly used by the chemist. When the vapour which passes over is to be condensed, the beak, or mouth of the retort, is fitted into a *receiver*, which may be kept cold by immersion in cold water, or in some other way(58).

Retort, Receiver, and Lamp.



Retort and lamp. Receiver and stand.

Emily. I had some idea of distillation before, but by no means a clear one. I always thought that there was something complex and mysterious about the process, instead of that perfect simplicity which I now see in it.

Mrs B. The effects of caloric, which have formed the subject of the present conversation, form a regular series, and generally take place in uniform succession. Expansion, liquefaction, and vaporization, appear to be produced in obedience to one general law. There is, however, another effect of caloric apparently altogether disconnected with them, and that is IGNITION, or incandescence, by which is meant that emission of light which is produced in bodies at a very high temperature; all substances being capable of becoming red hot, and of emitting light, as well as heat(59).

Emily. You mean, I suppose, that light which is produced by a burning body.

Mrs B. No; ignition is quite independent of combustion. Clay, chalk, and indeed all incombustible substances may be made red hot. When a body burns, the light emitted is the effect of a chemical change which takes place, whilst ignition is the effect of caloric alone, and no other change than that of temperature is produced in the ignited body. By combustion a body is decomposed, and it therefore can be performed on the same substance but once, whilst ignition can be induced in the same body any number of times. Combustion requires the presence of air, ignition that of heat only(60).

All solid bodies, and some liquids, are susceptible of ignition, or in other words, of being heated so as to become luminous; and it is remarkable that in a situation perfectly dark, this takes place at the same temperature in all bodies, that is somewhere between 600 and 800 degrees of Fahrenheit's scale(61).

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57. Describe the glass alembic.
58. What is most commonly used for distilling by the chemist?
59. What is *ignition* or *incandescence?*
60. What is the difference between this light, and that from combustion?
61. At what temperature does it occur, and in what bodies?

Emily. But how can liquids attain so high a temperature, without being converted into vapour?

Mrs B. It would certainly be extremely difficult to bring the more volatile liquids to such a temperature, and it could only be done by confining them in a vessel of immense strength, in order to be able to resist the elasticity of vapour so highly heated. But if they were so confined, and this vessel then heated to ignition, its contents must be so also(62).

There are many speculations with respect to the sources of the light of ignition, but as little that is satisfactory is known on this point, it would be unwise in us to discuss it. At our next meeting we shall converse about latent heat, which is a subject sufficiently important to claim your undivided attention.

CONVERSATION VI.

ON COMBINED CALORIC, COMPREHENDING SPECIFIC AND LATENT HEAT.

Bodies have different Capacities for Heat. Proof by different Metals. Mercury and Water compared. Rarefaction and Condensation. Distinction between Specific and Latent Heat. Change of Form. Mixture of heated Water and Ice. Heat latent in Steam and Vapour. Condensation of Steam. Snow and Salt as a freezing Mixture.

Mrs B. We are now to examine the other modifications of caloric, but in order to enable you to understand them, it will be necessary to enter into some previous explanations.

It has been discovered by modern chemists, that bodies which differ in their natures from each other, though heated to the same temperature, do not contain the same quantity of caloric(1).

Caroline. How could that be ascertained? Have you not told us that the absolute quantity of caloric which bodies contain was entirely unknown to us?

Mrs B. True, but at the same time I said that we were enabled to form a judgment, by means of the thermometer, of the proportion in which it entered into bodies between certain temperatures. This, however, is true as respects any one species of matter only, as water for example. Thus, if we raise a given portion of the fluid 10°, it will require an equal addition of caloric to raise it another 10°; but it is found that, in order to raise the temperature of different bodies the same number of degrees, different quantities of caloric are required for each of them. If, for instance, you place a pound of lead, a pound of chalk, and a pound of milk, in a hot oven, they will be gradually heated to the temperature of the oven; but the lead will attain it first, the chalk next, and the milk last, and they will be found to have absorbed from the oven very different quantities of caloric(2).

Caroline. I do not see that one substance taking longer time than another to become heated, proves that more caloric is required, to produce this effect, in one case than in the other; as such a difference must necessarily arise from the difference in the conducting power of the bodies. The lead,

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62. In what way might a fluid be made red hot?

1. What has been discovered respecting the caloric contained in bodies?

2. What exemplifications are given of this fact?

for instance, conducts so much better than either of the others, that it must, of course, be the most quickly heated(3).

Mrs B. Your reasoning is very good, as far as conducting power is concerned; but facts, as established by decisive experiments, overturn your theory, and leave no doubt that the quantity of caloric which enters into various substances to produce in them the same thermometric effect, is very different; and hence they are said to possess different capacities for caloric.

Caroline. What do you mean by the *capacity* of a body for caloric?

Mrs B. I mean a certain disposition of bodies to require more or less caloric for raising their temperature to any given degree of heat(4). Perhaps the fact may be illustrated thus:

Let us put as many marbles into this glass as it will contain, and pour some sand over them; observe how the sand penetrates and lodges between them. We shall now fill another glass with pebbles of various forms; you see that they arrange themselves in a more compact manner than the marbles, which, being globular, can touch each other by a single point only. The pebbles, therefore, will not admit so much sand between them; and consequently one of these glasses will necessarily contain more sand than the other, though both of them be equally full.

Caroline. This I understand perfectly. The marbles and the pebbles represent two bodies of different kinds, and the sand the caloric contained in them; and it appears very plain, from this comparison, that one body may admit of more caloric between its particles than another(5).

Mrs B. Although I have used the pebbles and the marbles to enable you the more readily to lay hold of the idea, you must not consider this as a satisfactory explanation of the fact; for were it so, the capacities of bodies would diminish in the exact ratio of their density, which is by no means the case; for, although, in general, the most dense bodies have the least capacity, this is far from being uniformly the case. Oil occupies more space than an equal weight of water, and yet it has but one half the capacity for caloric; as that quantity which would raise a pound of water 10° would produce double that effect upon a pound of oil, raising it 20°(6).

We are unacquainted with the cause of difference of capacity, and whenever we call to our aid the operation of grosser matter, in illustrating the effects of imponderable agents, you must always consider it as you would a figure in poetry, as bearing only an imaginary relationship to the fact(7).

Emily. But I cannot conceive why the body that contains the most caloric should not be of the highest temperature; that is to say, feel hot in proportion to the quantity of caloric it contains.

Mrs B. The caloric that is employed in filling the capacity of a body, is not free caloric; but is imprisoned, as it were, in the body, and is therefore imperceptible: for we can feel only the caloric which the body parts with, and not that which it retains.

Caroline. It appears to me very extraordinary, that heat should be confined in a body in such a manner as to be imperceptible.

Mrs B. If you lay your hand on a hot body, you feel only the caloric which leaves it, and enters your hand; for it is impossible that you should be sensible of that which remains in the body. The thermometer, in the same

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3. What objection does Caroline make to these examples?
4. What reply is given, and how is this property designated?
5. By what example is this property illustrated?
6. Why is not this illustration to be considered as an explanation?
7. How are we to consider such illustrations?

manner, is affected only by the free caloric which a substance transmits to it, and not at all by that which it does not part with(8).

Caroline. I begin to understand it; but I confess that the idea of insensible heat is so new and strange to me, that some time is requisite to render it familiar.

Mrs B. Call it insensible caloric, and the difficulty will appear much less formidable. It is indeed a sort of contradiction to call it heat, when it is so situated as to be incapable of producing that sensation. Yet this modification of caloric is commonly called SPECIFIC HEAT(9).

Caroline. But it certainly would have been more correct to have called it *specific caloric.*

Emily. I do not understand how the term *specific* applies to this modification of caloric.

Mrs B. It applies to the relative quantity of caloric which different kinds or *species* of bodies, equal in quantity and temperature, are capable of containing. The term, therefore, you must recollect, does not apply to the heat, but to the matter with which it is united. Thus oil is one species, or kind, of matter, and water is another(10); you have already learned that they are differently expanded by equal quantities of caloric, and you are now to understand that by equal portions of it they are also differently heated; this arising undoubtedly from the peculiar constitution of the bodies, with which we do not pretend to be acquainted(11).

Caroline. Can you, Mrs B., show us any of the experiments to which you have alluded; as the mere fact that bodies of different kinds require different periods of time to bring them to an equal degree of temperature, certainly cannot prove any thing more than that they conduct heat in different degrees.

Mrs B. The difficulty you urge would indeed be a very serious one, if we could not, by reversing the experiment, prove that the milk, the chalk, and the lead, had actually absorbed different quantities of caloric; but this we can do by cooling the several bodies to the same degree, in an apparatus adapted to receive and measure the caloric which they give out(12). Thus, if you plunge them into three equal quantities of water, each at the same temperature, you will be able to judge of the relative quantity of caloric which the three bodies contained, by that which, in cooling, they communicate to their respective portions of water: for the same quantity of caloric which they each absorbed to raise their temperature, will abandon them in lowering it; and, on examining the three vessels of water, you will find the one in which you immerse the lead to be the least heated; that in which you put the chalk, the next; and that which contains the milk will be heated the most of all(13).

I have a very convenient way of performing the experiment by means of these three balls of metal, one of which is copper, another tin, and the third lead, each of them weighing exactly eight ounces. I suspend them by a thread in boiling water, and they will all, consequently, be heated exactly alike, that is to 212°. I now suspend them in three separate tumblers of cold water, a thermometer in each standing at 36°. As the water is equal in

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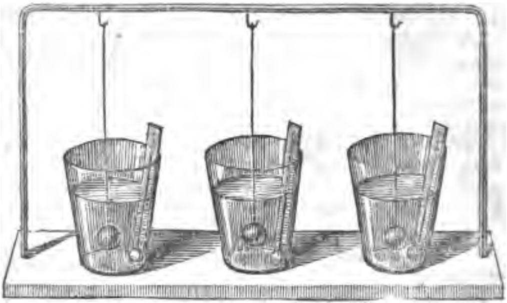
8. Why is the heat of capacity insensible?
9. What is this modification of caloric called, and what remark is made?
10. How is the term *specific heat* applied?
11. What analogous fact is mentioned?
12. On what principle can the fact be shown?
13. How may this be applied?

quantity and temperature, if the three balls contain equal quantities of caloric, what will be the effect upon the water?

Heated balls of Copper, Lead and Tin, immersed in cold water



Copper. Lead. Tin.

Emily. Why certainly it will be heated alike by the metals.

Mrs B. But what will be the result if the metals, although of the same temperature, contain unequal quantities of caloric?

Emily. In that case the one having the greatest capacity will, of course, in cooling down, heat the water the most.

Caroline. The difference is very plain. The copper has raised the thermometer the most, the tin next, and the lead least of all(14).

Mrs B. And that is exactly the order of their capacities; they being to each other as 114, 60 and 42. That is, if the copper required a quantity of caloric represented by the number 114 to elevate it a given number of degrees, the same effect would be produced on the tin by the quantity 60, and on the lead by 42(15).

Emily. I think that I have found a comparison for specific heat, which is very applicable. Suppose that two men of equal weight and bulk, but who required different quantities of food to satisfy their appetites, sit down to dinner, both equally hungry; the one would consume a much greater quantity of provisions than the other, in order to be equally satisfied.

Mrs B. Yes, that is very fair; for the quantity of food necessary to satisfy their respective appetites, varies in the same manner as the quantity of caloric requisite to raise, equally, the temperature of different bodies(16).

Emily. The thermometer, then, affords no indication of the specific heat of bodies.

Mrs B. None at all; no more than satiety is a test of the quantity of food eaten. The thermometer, as I have repeatedly said, can be affected only by free caloric, which alone raises the temperature of bodies.

But there is another mode of proving the existence of specific heat, which affords a very satisfactory illustration of the general fact. I did not introduce it before, as I thought it might appear to you rather complicated. It is this; if you mix two fluids, equal in quantity, but of different temperatures, let us say the one at 50, and the other at 100 degrees, of what temperature do you suppose the mixture will be?

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14. What experiment is mentioned, and what its result?
15. Whatare the order and proportion of their capacities?
16. By what comparison is the nature of capacity illustrated?

Caroline. It will be, no doubt, the medium between the two, that is to say, 75 degrees.

Mrs B. That will be the case if the two bodies happen to have the same capacity for caloric; but if not, a different result will be obtained(17). Thus, for instance, if you mix together equal weights of warm mercury and cold water in a jar, they are far from producing a mean temperature; but that of the mixture will be much below it. Suppose the temperature of the mercury to have been 156°, and the water 40°; the mean of these would be 98°, but the resulting temperature will be only 44°. Here then the mercury has lost 112°, whilst the water has gained only 4°(18).

If, on the contrary, the water be heated to 156° and the mercury to 40°, the temperature of the mixture will be 152°. The water in this case has lost only 4°; but this, in entering into the mercury, has elevated it 112°. In both these instances the capacity of water is evidently twenty-eight times that of mercury; or the caloric which would elevate a pound of water 1° would elevate a pound of mercury 28°(19).

Emily. But, Mrs B., it would appear to me more proper to compare bodies by *measure*, rather than by *weight*, in order to estimate their specific heat. Why, for instance, should we not compare *pints* of water and of mercury, rather than *pounds* of those substances; for equal weights may be composed of very different quantities?

Mrs B. You are mistaken, my dear; equal weights must contain equal quantities of matter; and when we wish to know what is the relative quantity of caloric which substances of various kinds are capable of containing under the same temperature, we must compare equal weights, and not equal bulks, of those substances. Bodies of the same weight may undoubtedly be of very different dimensions; but this does not change their real quantity of matter(20).

The comparison, however, has been made in equal volumes as well as in equal weights, and the results in either way are equally various; the general law may therefore be considered as established, *that different bodies in equal quantities, whether estimated by weight or volume, contain, at any given temperature, unequal quantities of caloric*(21).

Caroline. If all different bodies have different capacities for caloric, I do not see why the same body may not change its capacity at different temperatures; and, in that case, the thermometer would not be an accurate guide to inform us of the real quantity of caloric which left or entered into any substance, as this quantity would differ in high and in low temperatures(22).

Mrs B. Very judiciously remarked indeed. Much discussion has taken place, and many experiments have been made to ascertain this point; and these have resulted in proving that the capacities of bodies generally increase as their temperatures become elevated(23). The probability of this had been inferred, from our being able to increase the temperature of a body by merely condensing it, and to decrease it by rendering it more rare. Thus a smith can take a piece of cold iron, and, by hammering it smartly, heat it sufficiently to light a match, and kindle his fire. In this case the

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17. What other mode is given, and what remark is made upon it?
18. Give the experiment with mercury and water at different temperatures.
19. What is the result when the experiment is reverse
20. For what reason are equal weights taken?
21. What is the result with equal volumes, and what law .s deduced?
22. What remark does Caroline make?
23. What appears to be the fact in this particular?

only change produced in the iron is, that it has been condensed by closing its pores, and, consequently, a portion of the heat which was before latent, as caloric of capacity, has been forced out and appears in the form of sensible heat(24).

Emily. That is both curious and convincing, and it would follow, that if we could rarefy the iron, its capacity would be increased, and I suppose it would become colder; but how are we to do this?

Mrs B. We cannot mechanically rarefy a solid; but by experimenting with common air, instead of with iron, I can readily show you the effect both of rarefaction and condensation. I place a thermometer under the receiver of the air pump, and rapidly exhaust the air; do you see any change in the thermometer?

Emily. Yes, it has actually sunk three or four degrees, and appears to be still descending(25).

Mrs B. Now observe again; by condensing the air, suddenly, in this brass tube, which you have frequently seen used, a degree of heat will be given out sufficient to set fire to tinder. You therefore see, in the same substance, the effect of rarefaction in increasing, and of condensation in decreasing capacity(26).

As bodies are expanded, and rendered more rare, by increase of temperature, the inference seems natural that as they become expanded their capacities should also increase; and under these circumstances, if caloric be communicated to them, one portion of it goes to satisfy this increased capacity, whilst another serves to elevate the temperature(27). But let us now proceed to LATENT HEAT.

Caroline. And pray what kind of heat is that? I had thought that heat of capacity was sufficiently latent, as it is completely hidden in a body, producing no apparent effect upon it. How, I wonder, can any thing be more latent than this?

Mrs B. The heat of which I speak is another modification of combined caloric, which is so analogous to specific heat, that many chemists think it unnecessary to make any distinction between them; but the term *specific heat* is generally confined to that portion which goes to satisfy the capacity of a body, whilst its form remains unchanged, and we denominate *latent heat* that portion of caloric which is employed in changing the state of bodies, that is to say, in converting solids into liquids, or liquids into vapour(28). When a body changes its form from solid to liquid, or from liquid to vapour, a sudden and considerable increase of capacity for heat uniformly accompanies the change, and in consequence of this it immediately absorbs a quantity of caloric, which becomes fixed in the body it has transformed; and as it is perfectly concealed from our senses, it has obtained the name of *latent* heat(29).

Caroline. I think it would be much more correct to call this modification latent caloric than latent heat, since it does not excite the sensation of heat.

Mrs B. It was discovered and named by Dr Black long before the French chemists introduced the term caloric, and we must not presume to change the name, as it is still used by much better chemists than ourselves. Besides, you are not to suppose that the nature of heat is altered by being

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24. What effect is produced by hammering iron, &c.?
25. How may the effect of rarefaction be shown by the air pump?
26. What effect may be produced by condensing air?
27. What inference may be drawn from these facts?
28. What distinction is made between *specific* and *latent* heat?
29. Under what circumstances does heat become latent?

variously modified: for if latent heat and specific heat do not excite the same sensation as free caloric, it is owing to their being in a state of confinement, which prevents them from acting upon our organs; and, consequently, as soon as they are extricated from the body in which they are imprisoned, they return to their state of free caloric(30).

Emily. But I do not yet clearly see in what respect latent heat differs from specific heat; for they are both of them imprisoned and concealed in bodies.

Mrs B. Specific heat is that which is employed in filling the capacity of a body for caloric, in the state in which this body actually exists; while latent heat is that which is employed only in effecting a change of state, that is, in converting bodies from a solid to a liquid, or from a liquid to an aeriform state. But I think, that in a general point of view, both these modifications might be comprehended under the name of *heat of capacity*, as in both cases the caloric is equally engaged in filling the capacity of bodies(31).

I shall now show you an experiment, which I hope will give you a clear idea of what is understood by latent heat.

The ice which you see in this phial has been cooled by certain chemical means, (which I cannot well explain to you at present,) to five or six degrees below the freezing point, as you will find indicated by the thermometer which is placed in it. We will expose it to the heat of the fire, and you will see the thermometer gradually rise, till it reaches the freezing point——

Emily. But there it stops, Mrs B., and yet the fire burns just as well as before. Why is not its heat communicated to the thermometer?

Caroline. And the ice begins to melt; therefore it must be rising above the freezing point.

Mrs B. The heat no longer affects the thermometer, because it is wholly employed in converting the ice into water. As the ice melts, the caloric becomes *latent* in the new formed liquid, and therefore cannot raise its temperature; and the thermometer will consequently remain stationary, until the whole of the ice be melted(32).

Caroline. Now it is all melted, and the thermometer begins to rise again.

Mrs B. Because the conversion of the ice into water being completed, the caloric no longer becomes latent; and therefore the heat which the water now receives raises its temperature, as you find indicated by the thermometer(33).

Emily. But I do not think that the thermometer rises so quickly in the water as it did in the ice, previously to its beginning to melt, though the fire burns equally well.

Mrs B. That is owing to the different specific heat of ice and water. The capacity of water for caloric being greater than that of ice, more heat is required to raise its temperature, and therefore the thermometer rises slower in the water than it did in the ice(34).

Emily. True; you said that a solid body always increased its capacity for heat by becoming fluid, and this is an instance of it.

Mrs B. Yes; and the latent heat is that which is absorbed in consequence of the increased capacity resulting from the change of form. This increased capacity in the water is not the result of expansion, but merely of the change to the liquid state, for the water is in fact more dense than the

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30. Who discovered latent heat, and what is remarked respecting it?
31. What further is said of the distinction between specific and latent heat?
32. What experiment is detailed showing the absorption of heat?
33. What occurs after the snow has melted, and why?
34. Why did the thermometer rise most rapidly in the snow?

ice, as you may know by the floating of ice upon water(35). You have already learned that in rendering a substance liquid, the caloric is employed in modifying the attraction of the particles so as to produce the fluid form; and whilst so employed it evidently must be latent, for if it could pass into your hand, or into any thing else, in the form of free caloric, it must, in that case, leave the water, and this would be brought back to the state of ice(36). The caloric employed in rendering bodies liquid is frequently called the *caloric of fluidity*(37).

Caroline. Have you any means of ascertaining the quantity of heat which is rendered latent in the conversion of ice into water; for it would seem, from the length of time required to melt the ice before the fire, that it must be very considerable?

Mrs B. We can fortunately do this at once, as there is now dry snow upon the ground. I have ordered a pound of it to be weighed, and put into a wooden bowl, and you see that a thermometer, placed in it, stands at 32°. In this cup I have a pound of water which is heated, as you perceive, to 172°, or within 40° of boiling. This I pour upon the snow, and stir it about; now you see the snow has thawed.

Emily. Yes! and what is most surprising, the thermometer in the bowl still stands at 32°. I had been calculating that the mean was 102° and although I expected to see it below this, I never should have believed that all the heat would be lost(38).

Caroline. The pound of hot water has actually lost 140° of heat, and the whole of this must have become latent in converting the same weight of ice into the fluid form. What an enormous quantity of heat there must be in the water of the ocean! If it could at once become sensible heat, the water would all be ready to boil(39).

Emily. What would have been the effect if the water in the cup had been heated to 176° instead of 172°. Would the temperature of the mixture then have been 32°?

Mrs B. By no means: 140° would still have disappeared, and the 4° of excess would have been diffused throughout the two pounds of water, so that the thermometer would have stood at 34°(40).

We might perform many other experiments in confirmation of the fact just explained; but we have much to do, and one or two convincing and unexceptionable proofs are sufficient for our purpose; and indeed a greater number would be more likely to confuse than to instruct you. During our progress you will witness many experiments, which, whilst they are introduced to prove other points, will furnish additional evidence of the truth of that which I have just explained to you.

You have observed me place this flask, half filled with water, over the lamp. Within it are two thermometers, the bulb of one immersed in the liquid, whilst the other is suspended above it. The water is near boiling, and I wish you to notice what takes place as it becomes converted into vapour.

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35. Does not the increased capacity result from expansion?
36. What reason is given why the caloric must be latent?
37. What other name is given to this modification of heat?
38. How may the loss of heat in melting ice be shown?
39. What quantity becomes latent, and how is this proved?
40. If the water had been heated to 176°, what would have been the result?

Caroline. The thermometer placed within the water is rising; it is now 212° and the water begins to boil, but the thermometer remains stationary, although heat must still be flowing in as rapidly as before; this is wonderfully curious! The caloric must now be busy in changing the water into steam, in which it hides itself, and becomes insensible. This is another example of latent heat producing a change of form. At first it converted a solid body into a liquid, and now it turns the liquid into vapour.

Mrs B. If you observe the thermometer which is placed above the liquid, and surrounded by the steam, you will see that it also stands at 212°; yet you will soon learn that the steam has absorbed a vast deal more heat than the ice did in thawing(41). If we were now to reverse these changes, and condense the vapour into water, and the water into ice, all the latent heat would reappear in the form of free caloric(42).

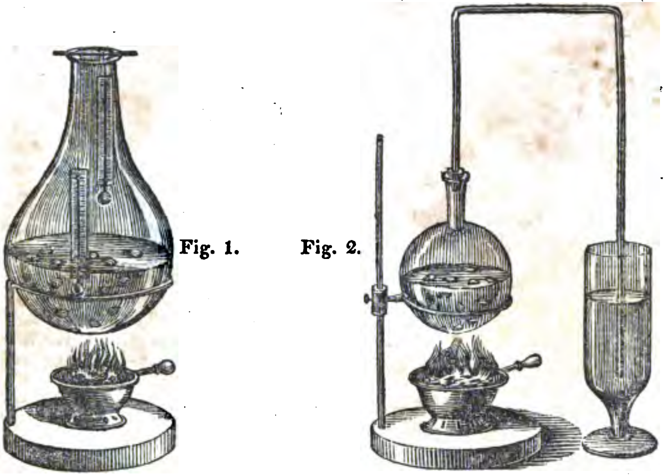

Fig. 1. Fig. 2.

[Fig. 1. Apparatus showing that boiling water and steam are equal in temperature. Fig. 2. Steam from boiling, condensed by cold water.]

Emily. Pray do let us see the effect of latent heat returning to its free state.

Mrs B. For the purpose of showing this, we need simply conduct the vapour through the tube into this vessel of cold water, where it will part with its latent heat and return to its liquid form(43).

Emily. How rapidly the steam heats the water!

Mrs B. That is because it does not impart to it its free caloric merely, but likewise its latent heat; and so great is the amount thus communicated, that when the water in the jar has had one ounce added to it by the condensation of the steam, this steam will have elevated its temperature about seven times as much as an ounce of boiling water would have done; and hence it results that an ounce of steam at 212°, contains seven times as

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41. Detail the experiment of boiling water in a flask, with the result.
42. What is it said would result from reversing the experiment?
43. How may this be effected?

much caloric as an ounce of water at the same temperature(44). By an easy calculation, therefore, it can be shown that steam contains a quantity of caloric in a latent state, which, if it could be confined within it, would, in the form of free heat, elevate its temperature to 950°; a portion more than sufficient to render it red hot(45). You may readily judge, therefore, why steam, issuing from boiling water, should scald so severely, although its quantity may be very small. When it comes into contact with the body, this being cooler, condenses it, and the steam gives out its latent heat(46).

Caroline. In natural evaporation, at common temperatures, the water which exists in the atmosphere in the form of vapour, must pass into that state without combining with such an enormous quantity of caloric.

Mrs B. On the contrary, it has been found that vapour at low temperatures contains more latent heat than that at 212°, its latent heat being increased in proportion as its sensible heat is diminished; so that if the temperature were 150° below the boiling point, the latent heat, instead of being 950°, would be 1100°(47).

We cannot perform the experiments which demonstrate this fact, but the proofs of it are quite satisfactory; and the importance of that law in the economy of nature, with its results, will, by and bye, be pointed out to you.

Emily. We have seen the latent heat of steam set free by the return of the steam to the liquid state. I should like also to see that of water given out on its conversion into ice.

Caroline. That must not only be difficult, but, I should suppose, impossible in this warm room.

Mrs B. So far from being impossible, it is by no means difficult. To freeze milk, requires a temperature somewhat below that for water; yet ice cream is made abundantly in summer. I believe, Caroline, you know the manner in which this is effected?

Caroline. Yes; the milk, or cream, to be frozen, is put into a metallic vessel, and this is placed within another vessel of wood, and surrounded by a mixture of ice and common salt, which produces a degree of cold sufficient to freeze the cream(48). I have often assisted in making it, but have never been able to understand why the mixing of salt, which itself is not cold, should produce a more intense cold than that of the ice alone, and particularly, as I have always observed that the salt causes the ice to melt, and must therefore communicate heat to it(49).

Mrs B. What you have just learned will enable you to solve the mystery. We will now mix some snow and salt in this tin cup; you see that they immediately begin to melt, and that the moisture of the atmosphere condenses on the outside, and forms a coat of ice(50).

Emily. The mixture feels much colder than the ice itself, and yet it is becoming liquid.

Mrs B. It is that very circumstance which causes the intense cold; and it was by this same means that Fahrenheit obtained the zero of his scale. You see that a thermometer placed in it sinks upwards of 32° below freezing, or to zero, represented by a 0°.

The cause of the intense cold of the mixture, is that change from the solid to the fluid state, by which its capacity for caloric is so greatly increased;

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44. What is the heat in steam compared with that in boiling water?
45. What is proved respecting the quantity of heat latent in steam?
46. Why does steam scald more violently than boiling water?
47. What is the fact respecting the latent heat of atmospheric vapour?
48. What is the process for making ice cream?
49. What puzzling circumstance does Caroline mention?
50. What is the effect of mixing snow and salt?

and of course, to satisfy this increased capacity, it must absorb caloric from the surrounding bodies, and consequently produce cold in them(51).

Caroline. I must have been stupid not to recollect that, as it follows of necessity from the doctrine of latent heat; but still I do not see why it should not itself freeze, as it is colder than ice, nor what can have become of the 32° which it has lost.

Mrs B. I am apprehensive that you will again lay claim to the crown of stupidity, however willing you may be to have your title disputed. If caloric be rendered latent when a body changes its form, it must first have been free. When the salt and snow melt, a portion of their own free caloric is converted into caloric of fluidity; but this being insufficient to satisfy the increased capacity, an additional portion is taken from the bodies in contact with the mixture, and thus their temperature is also lowered(52).

If we mix salt with water, the brine which we produce will not freeze until it is cooled some degrees below the freezing point of fresh water; the number of degrees depending upon the quantity of salt which has been dissolved. Sea-water therefore requires a more intense cold to freeze it than river water. When water is saturated with salt, its freezing point is lowered at least 32°, or down to 0°; and hence, whilst its temperature is above zero, it must remain fluid(53).

Emily. Whatever you put in this mixture, then, would freeze?

Mrs B. Not every liquid, but any one that is susceptible of freezing at that temperature. I have prepared another mixture of salt and snow, for the purpose of freezing the water from which you are desirous of seeing the latent heat escape. The snow and salt are in this tin cup, and I immerse in it a smaller vessel containing the water to be frozen. I have put a thermometer in the water, in order that you may observe its rate of cooling.

[Tin cup containing snow and salt, the inner vessel containing water to be frozen.]

Caroline. [illegible] thermometer descends, but the heat which the water is now losing is its *free*, not its *latent* heat.

Mrs B. Certainly; it does not part with its latent heat till it changes its state and is converted into ice.

Emily. But here is a very extraordinary circumstance! The thermometer has fallen below the freezing point, and yet the water is not frozen.

Mrs B. Such is always the case previously to the freezing of water, when it is in a state of perfect rest. Now it begins to congeal, and you may observe that the thermometer again rises to the freezing point(54).

Caroline. It appears to me very strange that the thermometer should rise the very moment that the water freezes; for it seems to imply that the water was colder before it froze than when in the act of freezing.

Mrs B. So it was; and after our long dissertation on this circumstance, I did not think it would appear so surprising to you. Reflect a little, and I think you will discover the reason of it.

Caroline. It must be, no doubt, the extrication of latent heat, at the instant the water freezes, which raises the temperature.

Mrs B. Certainly: and if you now examine the thermometer, you will find that its rise was but temporary, and lasted only during the disengage-

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51. What is the explanation?
52. What becomes of the caloric apparently lost?
53. What prevents the mixture from freezing at so low a temperature?
54. Detail the phenomena attending the freezing of water by snow and salt.

ment of the latent heat. Now that all the water is frozen, it again falls, and will continue to fall till the ice and mixture are of an equal temperature(55).

As there is some intricacy in this subject, I must not hurry you on too far. We will therefore dismiss it until to-morrow; and I can assure you that if you preserve a distinct recollection of the facts and explanations which have occupied us to-day, you will deserve no small praise.

CONVERSATION VII.

LATENT HEAT CONTINUED.

Heat rendered sensible by Solidification. Freezing by Evaporation and by Mixture. Natural Temperature, how equalized. Dew. Hoar Frost. Clouds. Fogs. Rain. Snow. Hail. Causes of Cold at great Heights.

Emily. I have been thinking, Mrs B., that if there were any liquids which would become solid by merely mixing them, their latent heat would be suddenly disengaged; are there any such?

Mrs B. I could show you several, and although you are not sufficiently far advanced to understand perfectly all the attending circumstances, I will exhibit to you one which will afford a striking example of the fact.

The fluid which you see in this phial is a solution in water of a certain salt called *muriate of lime.* In this other phial I have a saturated solution of *sulphate of soda,* (common Glauber's salt). On mixing and stirring them together, the whole, or very nearly the whole, will be rapidly converted into a solid mass(1).

Emily. How white it turns! I feel it quite warm, from the escape of the heat that was latent in the fluids, which have now changed into a solid substance like chalk. This is really one of the most curious experiments we have yet seen; it seems quite a miracle.

Mrs B. It is sometimes called the *chemical miracle;* and I think that even to the chemist, who is familiar with its cause, it must always appear highly interesting(2).

I will show you another instance similar to that of the water, which you observed to become warmer as it froze. I have in this flask a solution of sulphate of soda, (Glauber's salt,) made very strong; it was corked up whilst boiling hot, and kept without agitation till it became cold, as you may feel it now is. When I take out the cork and allow the atmosphere to press upon it, (for being closed when boiling, there is a vacuum in the upper part,) observe that the salt will suddenly crystallize.

Caroline. Surprising! how beautifully the needles of salt have shot through the whole flask!

Mrs B. The experiment succeeds sometimes, although the flask be not closely stopped, provided the solution be kept from all agitation. When the crystallization does not readily take place, a small piece of the solid salt dropped in will instantaneously produce it. But let us not forget the object of the experiment. Feel how warm the flask has become by the conversion of a part of the liquid into a solid.

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55. What are the causes of the rise and fall of temperature?
1. What two solutions become solid by mixture?
2. What law does this exemplify, and what is the phenomenon called?

Emily. Quite warm, I declare! This is a most curious exemplification of the disengagement of latent heat(3).

Mrs B. The slaking of lime affords another remarkable instance of the conversion of latent into sensible heat. Have you never observed how quick-lime smokes when water is poured upon it, and how much heat it produces?

Caroline. Yes; but I do not understand what change of state takes place in the lime that occasions its giving out latent heat; for the quick-lime, which is solid, is reduced to powder by the operation of slaking, and is, therefore, rather expanded than condensed.

Mrs B. It is from the water, not from the lime, that the latent heat is set free. The water combines with, and becomes solid in the lime; in consequence of which chemical union, the heat, which kept it in a liquid state, is disengaged, and escapes in a sensible form(4).

Caroline. I always thought that the heat originated in the lime. It seems very strange that water, and cold water too, should contain so much heat.

Emily. Then after this extrication of caloric, the water must exist in the lime in the state of ice, since it parts with the heat which kept it liquid.

Mrs B. It cannot properly be called ice, since ice implies a degree of cold, at least equal to the freezing point. Yet, as water, in combining with lime, gives out more heat than it does in freezing, it must be in a state of still greater solidity in the lime than when in the form of ice; and you may have observed that it does not moisten or liquefy the lime in the smallest degree(5). Quick-lime converts into the solid state about a third of its own weight of water. If more than this be added, the excess will remain in the liquid state, and moisten the lime. The former portion is chemically combined, the latter merely mixed(6).

Emily. But, Mrs B., the smoke that rises is white: if it was only pure caloric which escaped, we might feel, but could not see it.

Mrs B. This white vapour is formed by some of the particles of lime, in a state of fine dust, which are carried off by the caloric, united with a portion of water evaporated by the heat(7).

Emily. In all changes of form, then, a body either absorbs or disengages latent heat?

Mrs B. You cannot exactly say *absorbs latent heat*, as the heat becomes latent only on being confined in the body; but you may say, generally, that *bodies in passing from a solid to a liquid form, or from the liquid form to that of vapour, absorb heat; and that when the reverse changes take place, heat is disengaged.* To this law there are, it is true, some exceptions, which will be hereafter noticed(8).

Emily. We can now, I think, account for the ether boiling, and the water freezing in vacuo, at the same temperature.

Mrs B. Let me hear how you explain it.

Emily. The latent heat which the water gave out in freezing, was immediately absorbed by the ether, during its conversion into vapour; and, therefore, from a latent state in the water, it passed into a latent state in the vapour of the ether.

Mrs B. You are so far correct; but it remains to be explained why the temperature of the ether is, by its own ebullition, brought down to the freezing temperature of water. It is because that part of the ether which is

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3. What analogous experiment is given with sulphate of soda?
4. Whence is heat derived in slaking lime?
5. In what state does the combined water exist?
6. In what proportion is it rendered solid by the lime?
7. Of what does the white vapour which escapes consist?
8. What general law is given, and is it universal?

evaporated, must rob that portion which remains liquid of its free caloric, which it converts into a latent state. This cooled ether must cool the water; so that though one liquid boils, and the other freezes, their temperatures are equally reduced(9).

Emily. But why does not water, as well as ether, reduce its own temperature by evaporating?

Mrs B. It does so, in fact, though much less rapidly than ether. Thus, for instance, you may often have observed, in the heat of summer, how much any particular spot may be cooled by sprinkling it with water, although the water used may be as warm as the air itself(10). Indeed so much cold may be produced by the mere evaporation of water, that the inhabitants of India succeed in causing it to freeze, though the temperature of the air be as high as 40 degrees. This they do by availing themselves of the most favourable circumstances for the process, which their warm climate and dry atmosphere can afford, namely, the coolness of night, and situations most exposed to its drying breezes. The water is put into shallow earthen trays, so as to expose an extensive surface to the process of evaporation, and in the morning, the water is found covered with a thin cake of ice, which is collected in sufficient quantity to be used for purposes of luxury(11).

Caroline. How delicious it must be to drink liquids so cold in those tropical climates! But, Mrs B., could we not try that experiment?

Mrs B. Much, in this case, depends upon the rapidity of the evaporation, and this is materially influenced by the state of the atmosphere, which in our climate generally contains too much moisture to allow us to hope for success in such a trial(12). We are not, however, entirely without analogous facts. It has been often observed that wet clothes have frozen when hung out to dry, although the temperature of the air has been three or four degrees above freezing; the rapidity of the evaporation at the time of a brisk breeze and a dry atmosphere, being sufficient to produce the effect(13).

We can, upon a small scale, freeze water by its own evaporation in this very room, in which the thermometer stands at 70 degrees. For this purpose we must place some water in a shallow dish under the receiver of the air pump, and exhaust the air from it. What will be the consequence, Caroline?

Caroline. Of course the water will evaporate more quickly, since there will no longer be any atmospheric pressure on its surface; but will this be sufficient to make the water freeze?

Mrs B. No, because the vapour will not be carried off fast enough; but this will be accomplished, without difficulty, if we introduce into the receiver, in a large shallow vessel, some strong sulphuric acid, (oil of vitriol,) a substance which has a great attraction for water, whether in the form of vapour or in the liquid state. This attraction is such that the acid will instantly absorb the moisture as it rises from the water, so as to make room for the formation of fresh vapour. This will of course hasten the process, and the cold produced from the rapid evaporation of the water, will in a few minutes be sufficient to freeze its surface. We shall now exhaust the air from the receiver(14).

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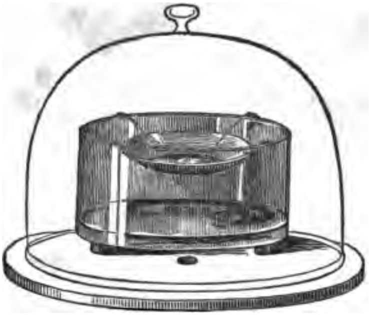
9. Can you give the rationale of the freezing of water by boiling ether?
10. What is remarked concerning the evaporation of water?
11. What is mentioned relating to the production of ice in India?
12. Why may not this be effected every where?
13. What circumstance occurs in our own climate dependent on this same principle?
14. How are we enabled to freeze water by its own evaporation?



[Plate of the air pump covered with a large receiver, under which is a glass vessel containing sulphuric acid, with a thin cup suspended above it, in which there is a portion of water to be frozen by its own evaporation.]

Emily. Thousands of small bubbles already rise through the water from the internal surface of the cup; what is the reason of this?

Mrs B. These are bubbles of air which were partly attached to the vessel, and partly diffused in the water itself; and they expand and rise in consequence of the atmospheric pressure being removed(15).

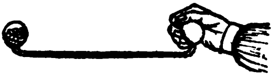
Caroline. See, Emily, the thermometer in the cup is sinking fast; it has already descended to 40°; it now stands stationary at 32°; and now crystals of ice are actually beginning to shoot out all over the surface of the water. How beautiful it is! The surface is now entirely frozen, but the thermometer remains at 32 degrees.

Mrs B. And so it will, conformably with our doctrine of latent heat, until the whole of the water is frozen; but it will then again begin to descend lower and lower, in consequence of the evaporation which goes on even from the surface of the ice itself(16).

Emily. This is a most interesting experiment; but it would be still more satisfactory if no sulphuric acid were required.

Mrs B. The method of forming ice which I have just shown you, was contrived by Mr Leslie, the inventor of the differential thermometer; but I will show you a freezing instrument, contrived by Dr Wollaston, upon the same principle as Mr Leslie's experiment, and by which water may be frozen by its own evaporation alone, without the assistance of sulphuric acid.

It is exactly similar in its form to the instrument invented by the celebrated Dr Franklin, which is sometimes, though very improperly, called a pulse glass; it would more properly be termed a *palm glass.*



[Palm, or Boiling Glass.]

This is Franklin's instrument. It contains some alcohol coloured red; and as the air is exhausted from it, there is a strong tendency in the alcohol to evaporate. If I grasp one of the bulbs in the palm of my hand, its warmth will expand the vapour, and drive the whole of the liquid into the other bulb, where, by the passing of the vapour through it, it will assume the appearance of boiling. At this instant, a distinct sensation of cold will be felt in my hand, in consequence of the film of alco-

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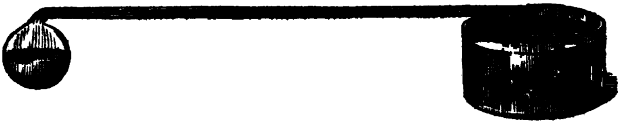
15. Of what do the bubbles which first escape consist?
16. How is the temperature affected in the progress of the experiment?

hol within the bulb becoming vapour, and in so doing absorbing caloric(17).

The instrument invented by Dr. Wollaston is, as you see, much larger than the palm glass, its length being four or five times as great. Like the latter its tube is terminated at each extremity by a bulb, one of which is half full of water. It is also perfectly exhausted of air, and consequently the water in the bulb is always much disposed to evaporate. This evaporation, however, does not proceed sufficiently far to freeze the water, because the vapour formed, presses upon the surface of the liquid and stops the process; but if the empty bulb be cooled by some artificial means, so as quickly to condense the vapour which rises from the water, the process may thus be so much promoted as to cause the water to freeze in the other bulb. Dr Wollaston has called this instrument a *Cryophorus* or *Frost bearer*(18).

Caroline. Cold seems to perform here the same part which the sulphuric acid acted in Mr Leslie's experiment?

Mrs B. Exactly so; but let us try the experiment. I pass the whole of the water into one bulb, and surround the other with a freezing mixture, This will condense the vapour which rises from the water into ice in the empty bulb; and the vacuum being thus kept up, the evaporation will soon rob the water of its caloric, and reduce the whole to the state of ice(19).



[Dr Wollaston's *Cryophorus*, with the empty bulb immersed in a mixture of snow and salt, for the purpose of condensing the vapour.]

By a process analogous to this, as well as by employing certain freezing mixtures, mercury itself may be frozen; although this requires a reduction of temperature of 71 degrees below the freezing point(20)

Emily. Then there must be some freezing mixtures which produce a cold much more intense than the snow and salt.

Mrs B. There is a great number; in some of which ice or snow is used, in others the cold is produced by the solution of different salts in water, taken at the ordinary temperature of the atmosphere, even in summer(21). I will show you one example of this. I have pulverized ten drachms of sal ammoniac, (muriate of ammonia), ten drachms of salt-petre, (nitrate of potassa), and sixteen drachms of Glauber's salt, (sulphate of soda), which I have in three separate papers. In this tumbler I have thirty-two drachms (four ounces) of water, and in this thin glass tube a portion of water which I intend to freeze. By mixing these salts in the water, and allowing the tube to stand in the mixture, the water within it will soon be frozen. The solid salts dissolve in the fluid, and in doing so will reduce the temperature from 50° to as low as 4° above zero(22).

When you are better acquainted with the different salts and acids, I will show you a table of their effects, by which you will see that we can command a degree of cold of nearly 100° below the freezing point.

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17. Describe the structure and operation of the *palm glass.*
18. What kind of instrument is the *Cryophorus?*
19. In what way may the water contained in it be frozen?
20. What is said respecting the freezing of mercury?
21. What is observed respecting freezing mixtures?
22. By what salts may water be readily frozen even in summer?

Caroline. Indeed, Mrs B., this subject of heat seems to have introduced us into a new world. We have hitherto witnessed all these changes in the temperature, and in the form of bodies, with scarcely any other than the simple impression that they were produced by heat and cold; but hereafter we shall be delighted to apply the valuable knowledge that we have gained, in tracing these changes in the atmosphere, on the earth, and in the water, to their causes, and must stand in perpetual admiration of the effects which result from them,—effects, of which, but for your kindness, it is probable we should have remained forever ignorant.

Mrs B. I shall be happy, my dear children, to live in your recollection as having, in some measure, contributed to the enlargement of your views of the works of nature; but more happy still, should your contemplation of these works habitually lead your minds to that of their great Author, the benevolence of whose character is as uniformly displayed in them, as are his attributes of wisdom and power.

As you have now obtained a pretty general view of the different modifications of which heat is susceptible, I will, before dismissing this subject, exhibit to you some further instances of their application principally in atmospheric changes. These have been already incidentally touched on, but you are now more fully prepared to comprehend them.

Caroline. What an astonishing effect must be produced by the evaporation which is constantly taking place from the whole surface of the earth, and from the condensation of this vapour in the form of dew or rain!

Mrs B. So general and so powerful is the influence from the absorption and evolution of caloric in these changes of form, that without their moderating effects it is certain that but a small portion of our earth would be habitable(23). If, as formerly supposed, air, instead of heat, had been the solvent of water, no result of this kind would have been produced; but, as it is, every particle of water that is evaporated, absorbs about 1000° of caloric, which, when the water is condensed, are again liberated(24). The ancients supposed that the equatorial regions must be uninhabitable, from the intensity of the heat; but the evaporation is proportionate to this intensity, and the vapour so formed ascends and carries off the heat in a latent state. When cooled in the upper regions of the atmosphere, or when wafted to colder climes, it is condensed, and, in the form of sensible heat, gives out the caloric which it had absorbed. Thus does invisible vapour become the transporter of heat from the torrid to the frigid zones(25).

Emily. And then the very freezing of water itself must contribute to the same end, as this, also, in becoming solid, gives out its latent heat(26).

Mrs B. The quantity of caloric thus communicated to the atmosphere by the freezing of water is exceedingly great. Count Rumford calculated that "the heat given off to the air, by each superficial foot of water in cooling *one* degree, is sufficient to warm an incumbent stratum of air, forty-four times as thick as the depth of water, 10 degrees(27)." In freezing it gives out the 140 degrees which, in its liquid form, remained latent; this will enable you to form some judgment of what must be its influence while undergoing this change of form from the fluid to the solid state. When we say that water gives out 140° of heat in becoming solid, we mean that in the

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23. What is said of the influence of the changes of form which occur in bodies?

24. What results from heat, instead of air, being the solvent of water?

25. How does the formation of vapour operate in equalizing temperature?

26. In what way does the freezing of water contribute its aid?

27. What calculation of Count Rumford is stated?

freezing of a given portion of water, a pint or a gill for example, as much heat is set free as would elevate the temperature of an equal quantity of water 140 degrees(28).

We know not how intense would be the cold which produces freezing, but for this counteracting influence; or how oppressive the heat which produces a thaw, but for the quantity rendered latent in the very operation.

Emily. Pray, Mrs B., in what manner do you account for the formation of dew?

Mrs B. *Dew* is a deposition of watery particles, or minute drops, from the atmosphere, precipitated by the coolness of the evening(29).

Caroline. This precipitation is owing, I suppose, to the cooling of the atmosphere, which prevents its retaining so great a quantity of watery vapour in solution as during the heat of the day.

Mrs B. Such was, from time immemorial, the generally received opinion respecting the cause of dew(30); but it has been very recently proved by a course of ingenious experiments of Dr Wells, that the deposition of dew is produced by the cooling of the surface of the earth, which he has shown to take place previously to the cooling of the atmosphere; for on examining the temperature of a plôt of grass just before the dew-fall, he found that it was considerably colder than the air a few feet above it, from which the dew was shortly after precipitated(31). This fact accounts very satisfactorily for the formation of white, or hoar frost. Whilst the temperature of the air is above the freezing point, that of certain articles on the surface of the earth becomes sufficiently reduced to condense and freeze the moisture which was contained in the atmosphere(32).

Emily. But why should the earth cool in the evening sooner than the atmosphere?

Mrs B. Because, by radiation, it parts with its heat more readily than the air. The earth is an excellent radiator of caloric, whilst the atmosphere does not possess that property, at least in any sensible degree. Towards evening, therefore, when the solar heat declines, and after sun-set, when it entirely ceases, the earth rapidly cools by radiating heat towards the skies; whilst the air has no means of parting with its heat but by coming into contact with the cooled surface of the earth, to which it communicates its caloric(33). Its solvent power being thus reduced, it is unable to retain so large a portion of watery vapour, and deposites those pearly drops which we call dew, or those glittering gems of which hoar frost consists(34).

Emily. If this be the cause of dew, we need not be apprehensive of receiving any injury from it; for it can be deposited only on surfaces that are colder than the atmosphere, which is never the case with our bodies.

Mrs B. Very true; yet I would not advise you for this reason to be too confident of escaping all the ill effects which may arise from exposure to the dew; for it may be deposited on your clothes, and chill you afterwards by its evaporation from them. Besides, whenever the dew is copious, there is a chilliness in the atmosphere which it is not always safe to encounter.

Caroline. Wind, then, should promote the deposition of dew, by bringing a more rapid succession of particles of air into contact with the earth,

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28. What is the quantity of heat set free in the freezing of water, and what is intended by so much being set free?
29. What is dew, and how is it said to be produced?
30. What opinion has been entertained respecting its precipitation?
31. What observation of Dr Wells has led to another theory?
32. In what way may this apply to the formation of hoar frost?
33. How does the earth cool to produce these effects?
34. Why does the air then deposite moisture?

just as it promotes the cooling of the earth and the warming of the atmosphere during the heat of the day.

Mrs B. This may be the case in some degree, provided the agitation of the air be not considerable; but when the wind is strong, it is found that less dew is deposited than in calm weather, especially if the atmosphere be loaded with clouds. These accumulations of moisture not only prevent the free radiation of the earth towards the upper regions, but themselves radiate towards the earth; for which reasons much less dew is formed than on fine clear nights, when the radiation of the earth passes without obstacle through the atmosphere to the distant regions of space, whence it receives no caloric in exchange(35). The dew continues to be deposited during the night, and is generally the most abundant towards morning, when the contrast between the temperature of the earth and that of the air is greatest. After sunrise the equilibrium of temperature between those two bodies is gradually restored by the solar rays passing freely through the atmosphere to the earth; and later in the morning the temperature of the earth gains the ascendency, and gives out caloric to the air by contact, in the same manner as it receives it from the air during the night(36).

Can you tell me, now, why a pitcher filled with cold water from a well or spring, or a bottle of wine taken fresh from the cellar (in summer particularly) will soon be covered with dew; and even the glasses into which the water or wine is poured will be moistened with a similar vapour?

Emily. The bottle being colder than the surrounding air, must absorb caloric from it. The moisture, therefore, which that air contained becomes visible, and forms the dew which is deposited on the bottle, the heat penetrating through the glass, which the moisture cannot do(37).

Mrs B. Very well, Emily. Now, Caroline, can you inform me why, in a warm room, or close carriage, the contrary effect takes place: that is to say, why the inside of the windows is covered with vapour?

Caroline. I have heard that it proceeds from the breath of those within the room or the carriage; and I suppose it is occasioned by the windows being colder than the breath, and, therefore, depriving it of part of its caloric, and by this means converting it into watery vapour(38).

Mrs B. You have both explained the facts extremely well. Bodies attract dew in proportion as they are good radiators of caloric, and it is thus that their temperature is reduced below that of the atmosphere. Hence we find that little or no dew is deposited on rocks, or sand; whilst grass and living vegetables, to which it is so highly beneficial, obtain it in abundance, another remarkable instance of the bounty of Providence(39).

Emily. We read that in some hot climates rain is scarcely known, and that the abundance of the dews serves to supply the moisture necessary to vegetation; but I do not understand what natural causes increase the dew in hot weather.

Mrs B. The more caloric the earth receives during the day, the greater will be the evaporation, and the more its loss by radiation during the night; and from both these causes the greater will be the deposition of the dew.

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35. What is observed respecting the effect of winds and clouds?
36. What is the process at night and in the morning?
37. What causes the dew, or moisture, upon a vessel containing a cold liquid, in a warm room?
38. What causes the moisture on the inside of the windows, in cold weather?
39. Why is dew deposited on some bodies more than upon others?

During a calm and clear night, a thermometer on the ground may be 12° lower than one hung in the air, owing entirely to this free radiation(40).

Caroline. I have been thinking of the formation of clouds. I understand very well that they consist of the watery vapour which rises from the earth, and is partially condensed; but frequently they form, and appear very dense, and again disappear with great rapidity, not producing rain, but seeming to vanish entirely.

Mrs B. The causes of the changes which occur in the atmosphere, and which are studied under the name of *Meteorology*(41), have puzzled wiser heads than ours. They take place in regions too elevated, and are effected by circumstances too distant from us to admit of accurate investigation. They are undoubtedly governed by the laws which have been explained to you; but from the causes named, we can, in this case, make only a general application of these laws(42). Currents of warm and of colder air exist in the atmosphere. Whilst the quantity of heat is sufficient, the vapour is held in a state of perfect solution; when partially cooled, a condensation into clouds is the result. This, when it occurs on the surface of the earth, we call a fog(43). If the cooling influence is from any cause increased, the quantity of caloric, which served to keep the water in a state of vapour, being diminished, the watery particles approach each other, and form themselves into drops of water, which, being heavier than the atmosphere, descend to the earth(44). There are also other circumstances, and particularly the variation in the weight of the atmosphere, the changes which take place in its electrical state, &c. which may contribute to the formation of rain. This, however, I have already told you, is an intricate subject, into which we cannot more fully enter at present(45).

Emily. Snow, I suppose, is caused by the condensed vapour of the clouds freezing before it is formed into drops(46); but how hail can be produced, and particularly in the hot weather of summer, I cannot even guess.

Mrs B. You have learned in your geography, that, even near the equator, the highest mountains are covered with perpetual snow; and this must convince you that at every season, in very elevated regions, the temperature is below the freezing point(47). Hail is undoubtedly occasioned by the formation of drops of rain in a warm stratum of moist air with one that is dry and cold below it. In falling through this latter, the drops freeze, and, from their weight, fall with such rapidity to the earth, that the warm atmosphere has not time to produce any sensible effect upon them(48).

Caroline. I know that those who have ascended to a great height in balloons, have uniformly borne testimony to the severity of the cold, and certainly elevated mountains are every where covered with snow. Now I should have supposed that as in ascending in mid-day you approach the sun, if any difference were felt it would be of an opposite kind.

Mrs B. At the distance of nearly a hundred millions of miles from the sun, the approach of a few thousand feet could make no sensible difference in its effects(49).

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40. What occasions the abundance of dew at certain times and places?
41. What is intended by the term *Meteorology?*
42. What circumstances interfere with its investigation?
43. In what way are clouds and fogs produced?
44. How are they made to produce rain?
45. What circumstances are supposed to influence the result?
46. In what way is the vapour condensed into snow?
47. What proves that the cold is intense at great heights?
48. How is hail supposed to be produced?
49. Why is not the influence of the sun increased as you ascend at noon?

The coldness of elevated stations is, however, dependent upon a general law regarding radiant heat, which is, that *radiant heat passes through transparent media without heating them;* and as our atmosphere is perfectly transparent, there is no heat imparted to it from the solar rays, which arrive through it to the surface of the earth, without any diminution of their intensity(50).

Emily. But, Mrs B., if the atmosphere is not warmed by the passage of the sun's rays through it, how does it acquire heat?

Mrs B. Just as heat was communicated to the water which we boiled in the flask some time since. Opake bodies absorb the solar ray and become heated, and these communicate their heat to the portion of air in contact with them. It is the earth therefore which warms the atmosphere. The stratum of air which is immediately in contact with it, is heated by it, becomes specifically lighter, and rises, making way for another stratum of air, which is, in its turn, heated and carried upwards; and thus each successive stratum of air is warmed by coming in contact with the earth(51). You may perceive this effect in a sultry day, if you attentively observe the strata of air near the surface of the earth. They appear in constant agitation; for though it is true that the air itself is invisible, yet the sun shining on the earth rarifies the air, which rising, mixes with that of a greater density, in doing which its undulatory motion is rendered visible. The temperature of the surface of the earth is therefore the source from which the atmosphere derives its heat, though it is communicated neither by radiation, nor transmitted from one particle of it to another by the conducting power; but every particle of air must come in contact with the earth, in order to receive heat from it(52).

Caroline. Yet as the warm air rises from the earth, and the cold air descends to it, I should have supposed that heat would have accumulated in the upper regions of the atmosphere, and that we should have felt the air warmer as we ascended.

Mrs B. The atmosphere, you know, diminishes in density, and consequently in weight, as it is more distant from the earth. The warm air, therefore, rises only till it meets with a stratum of air of its own density; and it cannot ascend into the upper regions of the atmosphere until all the parts beneath have been previously heated. Besides, as it ascends it becomes more rare, and consequently has its capacity increased, and its sensible heat reduced. It is also wafted to colder regions, and performs its office of aiding in equalizing the temperature of the earth(53).

Caroline. Still, as the mountains which are covered with snow are similar to other portions of the earth, it appears to me that, according to our theory, they ought to become heated by the solar rays, and, of course, have the snow melted upon their surfaces.

Mrs B. You must recollect that they are surrounded by an ocean of cold air in constant motion, which is amply sufficient to carry off all the heat which their comparatively small surfaces allow them to absorb. In the upper regions the currents of air are as constant, and probably as regular, as the tides in the ocean(54).

Emily. Is it also a fact that glass, crystal, diamond, water, and all other transparent substances, allow the rays of heat to pass through them without acquiring any themselves?

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50. What is the effect of radiant heat upon transparent media?
51. How is the heat communicated to the atmosphere?
52. How may the fact of rarefaction of the air be observed?
53. What is consequent upon the ascent of heated air?
54. Why are high mountains but little affected by solar heat?

Mrs B. If perfectly transparent, this would be the case. The burning-glass collects the rays of heat to a focus, and itself remains cool. If you hold it so that the rays are concentrated in the middle of a vessel of clear water, the fluid will not become heated(55); but if a piece of any opake substance be placed at the focus, the water may soon be made to boil; or, if a portion of ink, or of any article which will impair its transparency, be mixed with the water, it will in like manner become heated by means of the glass, or by exposure to the rays of the sun(56). The most simple way of trying this experiment is to expose two bowls of water to the action of the sun, one dirty and one clean; you will find that the clean water will remain the longest cool. The containing vessel however must eventually become warm, and of course heat its contents(57)

We must now dismiss the separate consideration of the subject of heat; but we shall find it accompany us through all our chemical inquiries, in connexion with every change which you will witness. You will consequently be compelled to advert to the laws which have been explained to you, with a frequency which must render them perfectly familiar. Our next conversation will be on electricity.

CONVERSATION VIII.

ON ELECTRICITY.

Name. Appearances produced by Friction. Opinions respecting its Nature. Analogy with Heat. Positive and Negative. Theory of a single and of two Fluids. Electrical Machine. Conductors and Non-conductors. Spark and Shock. Leyden Jar. Insulation. Induction. Franklinian theory of the Leyden Jar. Lightning and Thunder.

Caroline. I feel a great deal of interest in the subject upon which we are now to converse; for although I have repeatedly witnessed electrical experiments, and have read something respecting them, electricity is still to me a subject of much mystery.

Mrs B. Nor can I promise entirely to draw aside the veil which now obscures it; for notwithstanding enough is known about it to convince us that, like caloric, it is an agent universally diffused, and of perpetual operation, yet of its intimate nature we cannot be said to know any thing(1). Some believe it to be simple, others view it as compound, and although it is generally denominated a fluid, there are eminent philosophers who have doubted its being a material agent, believing it probable, that, like attraction, it is a mere property of matter(2). It is necessary, however, for us to adopt some theory, for the purpose of connecting together the valuable and numerous facts which have been discovered respecting it; but let me enjoin it upon you to use this theory only as you would an *artificial memory*, to enable you to recollect what without its aid might be forgotten(3).

Caroline. I confess, Mrs B., that my ardour begins already to abate, for

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55. What is remarked respecting a burning-glass?
56. How may water be heated by such a glass?
57. How may the same fact be proved without a glass?
1. What is said of the electric fluid, and of our acquaintance with it?
2. What different opinions are entertained respecting it?
3. What is the proper use of a theory?

how can we feel any great interest in a science in which we know that so much uncertainty prevails. I like those which rest upon established principles, and which, when we have once learned, we have learned forever. I was in hopes that the new discoveries in electricity had thrown so great a light on the subject, that every thing respecting it would have been clearly explained; but it seems that whilst we are informing ourselves concerning it, we ought to think, all the time, that perhaps what we are so eager to learn is not true.

Mrs B. When we dismiss our sober reason and allow our ardour to run into enthusiasm, we are not in the right road for the discovery of truth. The facts which you will learn are not the less true because your powers are limited, and you therefore cannot discover their remote causes. You were satisfied, in your natural philosophy, to refer a great number of operations to gravitation; yet of the cause of gravitation you do not pretend to know any thing. If you must have absolute certainty, you must relinquish the physical sciences, and devote yourself to the pure mathematics, where every thing is as certain as that two and two make four; yet of the mathematics you will confess that you were not very fond, although you have made some progress in the study of them(4).

Caroline. Thank you, my dear madam, for your rebuke, the justice of which I feel, and will endeavour to profit by it. I believe the science of electricity is of modern origin, and therefore we ought not to look for as much perfection in it, as in some others.

Mrs B. The ancients had noticed that certain bodies, by being rubbed, acquired the property of first attracting and afterwards repelling light substances. One of the articles which does so in an eminent degree is amber; and (from *electron*, the Greek name of amber) the term electricity is derived(5). There are many other substances which possess this property; among them are glass, the resins, sulphur, wax, jet, silk, fur, and woollen(6).

I rub this large glass tube with a silk handkerchief, and you see that it first attracts, and afterwards repels this flock of cotton. The same effect you perceive takes place on rubbing this stick of sealing wax with a piece of dry flannel. If, after thus rubbing them, you present your knuckle to either of them, you will feel a slight sensation, and hear a hissing noise. Were you in the dark, you would likewise see flashes of light between the glass, or sealing wax, and the knuckle. These are denominated *electric appearances*(7).

Emily. I have frequently, in frosty weather, noticed similar appearances in parts of my dress, particularly in flannel and silk, and have sometimes felt a smart sensation from the sparks which have been emitted(8).

Mrs B. The friction of woollen against silk often excites electric appearances very strongly; and after becoming familiar with the subject, you will notice numerous other cases in which similar effects take place. Electricity is now generally regarded as a very subtile elastic fluid, present in all bodies. It is viewed as one of the most active principles in nature. It is the cause of thunder and lightning, of the phenomena of galvanism, and probably also of magnetism. It is so intimately concerned in chemical changes, as to have given plausibility to the notion that it is the cause of them(9).

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4. What is said respecting certainty in the physical sciences?
5. From what was the name *Electricity* derived?
6. What other substances besides amber possess this property?
7. Name the appearances produced by rubbing glass or sealing wax.
8. What does Emily mention that she has noticed?
9. What is observed respecting its nature and effects?

Caroline. If it is a principle so active, and so universally diffused, ought we not constantly to be sensible of its influence? Yet this appears to be rarely the case.

Mrs B. Perhaps you will be more sensible of its influence when you are more familiar with its effects; as you can now detect the influence of heat in cases where you did not formerly suspect it. If heat were equally diffused throughout all the bodies in nature, what means would you possess of knowing its effects?

Emily. I cannot perceive how, in that case, we could even know of its existence, or what idea we could have of heat and cold, as the temperature of all bodies would be alike; or rather there would be no such thing as temperature(10).

Mrs B. Very well said, indeed; your conclusions are quite logical. You will find a strong analogy in many points between caloric and the electric fluid; and one instance of it is furnished by the fact, that it is only by the disturbance of their equilibrium that we become acquainted with their existence(11). When a body contains less than its natural share of the electric fluid, it is said to be *negatively electrified*, and when more, to be *positively electrified;* but in either case the body is said to be excited(12). The best way of exciting substances is by friction. When two different bodies are rubbed together, it appears that one may possess the property of parting with a portion of its electricity to the other; in which case they will both be *excited*, the one *negatively*, and the other *positively*(13). Thus in the rubbing of the glass tube with the silk handkerchief, a part of the electricity of the silk attached itself to the glass. The former therefore was in a negative, the latter in a positive state, and each of them would have exhibited electrical appearances(14).

Caroline. In my late reading upon this subject, I had understood that there were two distinct fluids, one called *negative*, or *resinous* electricity, and the other *positive*, or *vitreous;* and that when a body was excited it contained an excess either of the one or the other(15).

Mrs B. Such is the opinion of some eminent philosophers, who have, of course, strong grounds upon which to found their theory: this, however, is a point which we cannot discuss at present. Those who believe in two fluids, teach that when these fluids are united, no electrical appearances exist, but that they neutralize each other. Thus, according to this opinion, in rubbing the silk and glass together, the electricity in each was decomposed; the positive electricity of the silk going over to the glass, and the negative electricity of the glass to the silk, and each therefore contained an excess of the electric fluid, but of the opposite kinds(16).

Emily. It seems to me more natural to admit of but one electric fluid, and to suppose that the negative state is merely a privation of electricity, as cold is a privation of heat, and the positive state an excess of it, like one body being hotter than another.

Mrs B. The able founder of this opinion was our eminent countryman Franklin, and I believe that its supporters form a large majority among men of science(17). We must not, however, consider this question as one

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10. If heat were equally diffused, what would be the result?
11. What analogy is there between heat and electricity?
12. When is a body said to be negatively, and when positively electrified?
13. When electricity is excited by friction, what is believed to occur?
14. How is this exemplified in rubbing glass with silk?
15. What does Caroline observe that she had read?
16. What is the outline of the theory of two fluids?
17. Who was the founder of the theory of a single fluid?

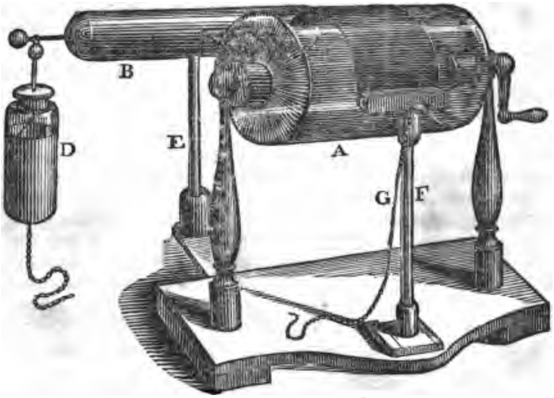
that may be settled by votes, or ourselves undertake to become judges upon such a subject. I shall adopt the theory of a single fluid, because I think it the more convenient, and confess that I am inclined to believe it to be the truth. This fluid, like heat, is repulsive among its own particles, but attractive of other matter, and has a tendency to an equilibrium(18).

Caroline. Pray, Mrs B., what was the origin of the terms *vitreous* and *resinous*, which it seems are synonimous with *positive* and *negative*(19).

Mrs B. They were adopted, because glass, and other vitreous bodies, when rubbed, generally become positively electrified, whilst resinous substances are thus rendered negative. The terms *plus* and *minus* are also sometimes used to designate an excess or a deficiency of this fluid(20).

There are but few subjects so fertile in striking facts and brilliant experiments as that of electricity; but we must touch but lightly upon it, or we should be detained too long from the pursuit of chemistry. I will now explain to you the structure of the common electrifying machine which we have upon the table, and you will find it perfectly analogous in its operation to the glass tube and silk handkerchief.

Electrical Machine.



[A, The cylinder. B, the prime conductor. C, the cushion. D, jar suspended from the prime conductor to receive a charge. E, insulating pillar of the conductor. F, insulating pillar of the rubber, or cushion. G, chain to connect the cushion with the ground, through the medium of the table, &c.

The back part of the machine is presented for the purpose of showing the cushion distinctly.]

The part called the cylinder, which is of glass, is made to revolve by means of the handle, and in so doing it rubs against a part at the back, called the cushion, or rubber, which is elastic, and covered with leather. During this revolving motion, a portion of the electricity of the rubber passes on to the surface of the glass, which, having an excess, will readily part with it to any *conducting* substance presented to it. Thus if you present your knuckle,

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18. What attractive and repulsive properties is this fluid said to possess?
19. What terms are used synonimously?
20. In what did these terms originate, and what others are employed?

to the side of the glass opposite the cushion, you will not only feel, but see and hear the fluid passing from it into your hand(21).

Emily. Then my hand is a *conductor* of the fluid. Glass, I believe, is called a *non-conductor.*

Mrs B. Electricity, like heat, passes with facility along some bodies, and very slowly indeed along others. The metals are the best conductors of electricity, as they are of heat also, and the electric fluid passes along them with inconceivable rapidity(22). All those bodies which become excited by friction are non-conductors; for if they conducted freely, the fluid would pass off as quickly as it was excited. They are also called *electrics,* because they become excited, or electrified, by friction. Conductors are also called *non-electrics,* because they are not excited by friction, or, if excited for a moment, have their equilibrium instantaneously restored by their conducting power(23). But to return to the machine.

Were we to continue turning the cylinder without presenting any conductor to it, the fluid would pass round it, and back again to the cushion. But you see in front of it a cylinder of metal, with points projecting from it towards the glass cylinder. These points receive the electric fluid with great facility, and it is immediately diffused over the *prime conductor,* which is the name given to this metallic body. You well know that very smart sparks may be taken by your knuckle, or any other good conductor which is brought near to it(24).

Caroline. When we take a shock, a glass jar coated with metal is always employed. What is the reason that the prime conductor alone will not give a shock when the machine is in action? I have often tried it, but never with success.

Mrs B. From its elasticity, resulting from the repulsion among its own particles, the electric fluid is constantly flying off from the prime conductor into the atmosphere. The quantity that can be retained by this part of the machine is, therefore, very limited, and affords no more than what is denominated the spark(25). The electrical jar, or Leyden phial, as it is frequently called, serves as a reservoir, in which the fluid can be retained in a state of comparative quiescence. You may frequently obtain sparks from the conductor to your hand at the distance of several inches, whilst a jar which may contain a thousand times the quantity, must be approached within half an inch in order to its discharge. I will presently explain to you the Franklinian theory of the action of the jar(26).

Emily. The prime conductor is placed upon a pillar of glass. This, I suppose, is because glass is a non-conductor, and serves therefore to prevent the escape of the fluid(27); but I do not understand why the cushion is also placed upon a glass pillar, as this is intended to supply the fluid to the cylinder.

Mrs B. You have judged correctly of the use of the pillar of the prime conductor. A conducting substance placed upon glass, or upon any other non-conductor, is said to be *insulated,* that is, its communication with bodies which would carry away any electricity communicated to it, is cut off. A person standing upon a stool with glass legs, or upon a cake of wax or rosin,

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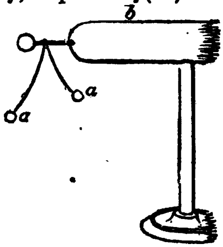
21. Describe the structure and operation of the electrifying machine.
22. What is said respecting *conductors* and *non-conductors?*
23. What bodies are called *electrics,* and what *non-electrics?*
24. What further is said of the machine, and its *prime conductor?*
25. Why can nothing more than a spark be obtained from it?
26. What is remarked respecting the Leyden jar?
27. What supports the prime conductor, and why is it so placed?

or any body that is suspended by threads of silk, is insulated(28). In the ordinary use of the machine the cushion is not insulated. You perceive that a brass chain hangs from it connecting it with the table. This is to afford to it a supply of the fluid, as it becomes exhausted by the turning of the cylinder. The glass pillar is placed there, in order that it may be readily insulated for the purpose of performing experiments with *negative electricity*. If you remove the chain, the native electricity of the cushion will be carried off by the cylinder and the prime conductor, and the cushion will be in a *negative* state, ready to receive sparks *from* your hand, or from any conducting substance presented to it(29).

Caroline. When I present my knuckle to the prime conductor, or to the brass knob of the cushion after removing the chain, the sensation and the appearances are the same; the rapid motion of the spark not allowing me to tell whether it flies from, or to, my knuckle. By what means then am I to discover whether a body be electrified negatively, or positively(30)?

Mrs B. This can be done with great facility. Two bodies which are in the same electrical state, either negative or positive, repel each other, whilst those which are in opposite states attract each other. When I hang this thread, with a cork ball at each of its ends, across the prime conductor, and turn the machine, they immediately recede from each other, both being positively electrified. If I hang a similar pair of balls upon the knob of the cushion, they also will repel each other, both being in a negative state; but one of those upon the prime conductor would be very strongly attracted by one upon the cushion, they being in *opposite states*. In order therefore to ascertain whether a body be positively or negatively electrified, all that is necessary is to suspend a cork ball by a silk thread, and then to communicate electricity to it by allowing it to touch the prime conductor, from which it will receive positive electricity. This ball will then be repelled by a body positively electrified, and attracted by one negatively electrified(31). There are also some very delicate instruments made for this purpose, which are denominated *electroscopes*, or *electrometers*(32).



[*a, a,* balls of pith or cork, suspended by a thread from the conductor *b.*]

Caroline. I do not clearly understand what is meant by *electricity by induction*. It is spoken of, in the books which I have read, as always taking place when an electrified body approaches one which is in its natural state. There seems to be something in it very difficult to comprehend(33).

Mrs B. I was about to call your attention to that point, as it is essential to the understanding of the mode in which the electrical jar receives its charge. We have considered the electrical fluid as being repulsive of itself, and as moving with great facility through conducting substances. When you place your knuckle near to the positively electrified conductor, your knuckle will become negatively electrified; a portion of its native electricity being driven out of it, and made to retire into your arm, by the repulsive agency of that contained in the conductor. Your knuckle is thus prepared to

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28. What is meant by *insulation?* and give the examples.
29. What is the object of insulating the cushion?
30. Can the direction of the electric spark be perceived?
31. How may we discover the state of an electrified body?
32. What are the instruments called, which are used for this purpose?
33. When does a body become electrified by *induction?*

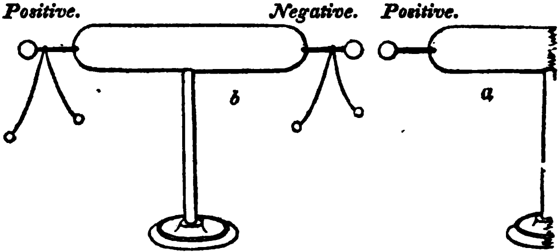
receive the spark, which, if it be sufficiently near, will fly to it, in order to restore the equilibrium(34). Whenever a body positively electrified is made to approach another in its natural state, it always occasions, or *induces*, the contrary or negative state in the latter; and it is therefore said to be electrified by *induction*, whilst the former was electrified by communication(35).

Emily. It seems strange that a body should become electrified without either losing or receiving electricity; as, if it does neither the one or the other, it must still possess its natural share.

Mrs B. Your objection appears natural, but still I think that by calling caloric to our aid, for the purpose of comparison, it will be easily obviated. If you take a bar of iron, and reduce the temperature of one of its ends ten degrees, and heat the other in the same proportion, will its absolute quantity of caloric be changed(36)?

Caroline. Certainly not; and I now think that I see through the mystery. The repulsive agency of the electricity in the charged body causes a portion of that in the second body merely to retire back; but it would then seem that this retiring portion must produce the positive state in the part to which it is driven(37).

Mrs B. Your reasoning is perfectly correct, and easily verified by experiment. I have here a second conductor, insulated like the prime conductor. Upon each end of this I have hung cork balls, and upon placing it within the influence of the charged prime conductor, but not sufficiently near to receive any of its electricity, both pair of balls will exhibit repulsion; but upon testing them we shall find that those which are nearest to the prime conductor are negatively electrified, whilst the more distant pair are in a positive state(38).



[*a*, Prime conductor of the Electrical Machine, positively electrified. *b*, a second insulated conductor, with pairs of pith balls suspended at each end.]

Emily. That is a very satisfactory experiment indeed, and makes the whole perfectly plain. Upon removing this second conductor away, out of the influence of the machine, the fluid within it will of course again distribute itself equally, and both pair of balls will collapse.

Mrs B. I now remove it, and such you see is actually the case(39). If time admitted I would show you some other very satisfactory illustrations

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34. What occurs as the knuckle approaches the conductor?
35. Upon what general law does this depend?
36. By what analogy is this illustrated?
37. How does Caroline explain this effect?
38. By what experiment is this fact exhibited?
39. How may the repelling balls be made to collapse?

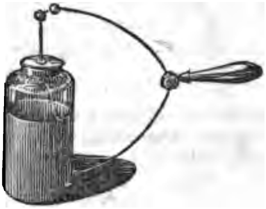
of this fact; but we must hasten to the explanation of the Leyden phial, so called from the discovery of it having been made at Leyden. A glass bottle, or jar, is covered both within and without, with a metallic coating, reaching to within two or three inches of the top, where the glass is left bare, so that there is no conducting communication between the inside and the outside. Through the neck of it passes a brass wire, which touches the inside coating, and having a knob at its outer extremity(40). If I present this knob to the prime conductor, the electric fluid will be conducted down the wire, and distributed over the inner surface of the glass by means of the metallic coating; a large quantity of the fluid can be thus accumulated, so as to give what is called a shock(41). A number of such jars united together form what is called an electrical *battery*(42).

Caroline. Then the jar is charged by communication. From your previous remarks I had supposed that induction was in some way concerned in the process.

Mrs B. You will find that the accumulation depends entirely upon induction: one or two sparks would otherwise cause the jar to be as highly charged as the conductor, and it would therefore be as much inclined to return what it had received, as to receive a larger portion. Glass, as well as other bodies, is believed to contain, naturally, a large quantity of electricity. When an additional portion passes into the jar, it acts by its repulsive agency through the glass, and drives off from its outer surface an equal quantity of that which was naturally contained there. One side thus becomes negative by induction, whilst the other becomes positive by communication. Successive portions are thus received, until no more can be expelled from the outer surface(43).

Emily. It would follow from this explanation that a charged jar, like the conductor with the two pair of balls, contained no more electricity than it did before it was charged(44).

Mrs B. And such is the theory proposed by Dr Franklin, and received by the greater number of philosophers. One side is positively, and the other negatively electrified, and the intervention of the glass prevents the restoration of the equilibrium. Sometimes however the force of the charge will be such as to cause it to perforate the glass, making a hole through which the fluid is discharged. The charge of the jar will, of course, pass through any conducting body which forms a connexion between its two sides. After charging this jar, I place one of the knobs of a discharging rod against the outside coating, and cause the other to approach the wire connected with the inside. The fluid leaves the inside, passes along the wire to the outside, and the equilibrium is thus restored(45).



[Electrical jar, or Leyden phial with a discharging rod.]

Caroline. And if I take the jar in one hand and then touch the knob with the other, the fluid passes through my arms and chest, and I feel the shock(46). I have frequently done this, and knew that it was necessary to touch both sides of the jar, but did not understand why it was so. How wonderful is this fluid, and how

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40. What is the structure of the Leyden, or electrical jar?
41. In what way is it made to receive the electric fluid?
42. What is meant by an electrical *battery?*
43. Give the general explanation of the charging a jar.
44. What is said respecting the quantity of fluid in a charged jar?
45. What is the mode of discharging a jar, and why?
46. How may the shock be made to pass through the arms?

interesting the study of it! I shall never again view experiments performed with the electrical machine as a mere thing of amusement, but shall trace the motions of the fluid, as I now do that of caloric, in changes which never before engaged my attention.

Emily. Pray, Mrs B., why is a jar or phial used; a bottle cannot be necessary to contain the electric fluid in the way in which it contains water?

Mrs B. The form is a mere matter of convenience. A flat pane of glass, properly coated with tin foil on each side, is equally effective, but is more easily broken, and not so readily handled, and is therefore seldom used(47).

I have spoken of friction as the means by which electricity is excited; but you are not to consider this as the only means. It appears to be brought into action by every chemical change. The mere contact of two different metals produces it; bodies become electrified by mere heating and cooling; evaporation and condensation also excite it; and it is probable that upon this circumstance depends the magnificent phenomena of lightning and thunder, which we so feebly imitate in our electrical experiments(48). The clouds formed by the partial condensation of the exhaled vapours frequently become surcharged with the fluid; this induces the contrary state in the earth beneath it, and the electricity flies from the cloud to the earth, exhibiting a vivid light, and causing those sounds which we call thunder, and which is the noise occasioned by the discharge, re-echoed again and again from the earth and distant clouds, until lost in the distance(49).

Emily. The air I suppose must be a non-conductor, or it would restore the equilibrium as fast as it was disturbed.

Mrs B. Were not the air an electric, we probably should know nothing of the phenomena of electricity. In thunder and lightning it acts the part of the glass in the Leyden jar: the cloud may be considered as one coating the earth as the other, whilst the air intervening completes the resemblance. The discharge takes place when the intensity of the charge is such as to enable it to overcome the obstacles presented by distance, and the resistance of the atmosphere(50).

You have now learned enough respecting common electricity to be able to pursue the subject alone, and we must hasten to that of *Voltaic Electricity*, or *Galvanism*, which, although of very recent discovery, has so powerfully aided the chemist in his researches, as almost to have produced a revolution in his science. We will enter upon this subject to-morrow.

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47. Is it necessary that a jar, or bottle, should be employed?
48. By what means other than friction may electricity be excited?
49. How is the production of lightning and thunder explained?
50. Is the air a conductor, and what is its influence in lightning?

CONVERSATION IX.

ON VOLTAIC ELECTRICITY, OR GALVANISM.

Discoveries of Galvani. Discoveries of Volta. Pile, Trough, and Couronne des tasses. Motors of Electricity. Action of Acids on Metals, applied to the Trough. Opinions of Volta, Wollaston, and Davy. Dr Hare's views. Calorimotor. Electro-Magnetism. Thermo-Magnetism.

Caroline. I believe, Mrs B., that the discovery of Galvanism, which we are to discuss to day, was altogether accidental; at least I have seen it so stated in some accounts of it.

Mrs B. And such is the case, to a certain extent, with almost every important discovery. There is, however, frequently a want of justice in ascribing discoveries to accident. Thousands of persons might have witnessed the fact noticed by Galvani, who would have considered it as merely a curious circumstance, and would have pursued it no further. Discoveries are made in the mind of the discoverer. It is the inquiries and researches suggested to the man who possesses intellectual acuteness, and is in the habit of patient investigation, which give to facts their value, as it is by these that their influence and connexions are ascertained.

Galvani was a professor of the university of Bologna, and about the year 1790 was engaged in a series of experiments with a view to prove that muscular motion was intimately connected with electrical action(1). Some dead frogs, intended to make soup for his lady, who was in ill health, were lying upon a table near an electrifying machine. A student, in the absence of Galvani, was amusing himself with the instrument, and noticed that convulsive motions took place in the muscles of one of the frogs, when touched by a piece of metal. This was observed, and communicated to her husband by Madam Galvani, a lady of great intelligence. A series of experiments was instituted by the professor, who thought that the facts which he ascertained lent powerful aid to the theory that he had adopted(2). He soon discovered the means of exciting these contractions at pleasure, by merely using two wires of different metals, independently of the electrical machine. He afterwards published his discoveries under the name of *animal electricity*(3).

Emily. If the contractions were produced by electricity, I do not see why two *different* metals were necessary to excite them; but I suppose that the mode of applying them will explain the reason.

Mrs B. The discovery of the true theory of the action of the metals was reserved for the celebrated Signor Volta of Italy, who was of opinion that the electricity did not exist in the animal, but that it was excited by the contact of the two different metals, was by them communicated to the muscle, and occasioned the convulsive motions, just as they may be produced by the ordinary machine(4). The sense of taste, and frequently that of sight, may be very readily brought into action in this way. I have here a

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1. Who was Galvani, and what was his pursuit at the period named?
2. What were the circumstances attending the discovery of Galvanism?
3. How did he excite muscular contractions?
4. Who discovered the true theory of the action of two metals?

dollar, and a piece of zinc about the same size, by which you can try the experiment. If you place the piece of silver *upon*, and the zinc *under* your tongue, and let the two metals project so that you can bring their edges into contact, you will, upon so doing, experience a very peculiar sensation.

Emily. Indeed I did; what a strong metallic taste, and I think something like heat; but I cannot describe it.

Mrs B. If you place one of the pieces between the gums and the upper lip, the other between the gums and the lower lip, then close your eyes, and let the metals touch, you will perceive the sensation of a flash of light. There are some persons, however, to whom this is not visible(5).

Caroline. In what way is the contact of the two metals supposed to produce this effect, and is it peculiar to silver and zinc?

Mrs B. By no means; any two *different* metals will produce it in some degree, but silver and zinc are among the most effective. Copper and zinc however are usually employed, and answer perfectly well(6). If a plate of copper and another of zinc be insulated, by furnishing them with glass handles, and they then be brought into contact by their flat surfaces, it will be found on separating them that the copper will be negatively and the zinc positively electrified(7). It appears therefore that when two different metals are brought into contact, one of them has the power to abstract electricity from the other, and thus to become positively electrified, whilst it reduces the piece with which it was in contact to the negative state(8). The electricity from a single pair of plates is but feeble, but can be rendered perfectly sensible by means of a delicate electroscope. From this property Volta, who was the author of this discovery, denominated the metals *motors* of electricity, and the process *electro-motion*(9).

Emily. You say that electricity from a single pair of plates is feeble: can it be increased by using a larger number, or in any other way?

Mrs B. Volta, considering that the zinc had the power of moving some of the electricity from the copper into itself, imagined that if this result could be obtained through a number of successive pairs, the effect would be proportionally increased; and proceeding upon this idea he constructed the VOLTAIC PILE, of which he published an account in the year 1800(10). This pile he constructed by taking an equal number of plates of copper, of zinc, and of pieces of cloth cut a little smaller than the metallic plates. The cloth he moistened in a solution of salt in water; these were piled upon each other, by first placing a piece of zinc on a round block of wood, upon that a piece of copper, and then a moistened cloth; this arrangement he continued—zinc, copper, cloth; zinc, copper, cloth—until thirty, forty, or fifty of each were piled up. If the pile began with zinc, it ended with copper; the electro-motive effect increasing with the number of plates. It was now found that the zinc end of the pile was highly positive, and the copper end highly negative; and if a finger of one hand was placed in contact with the lower plate, and the upper plate touched with the other hand, a shock was felt very similar to that from the common electrifying machine(11). I have not a pile of this sort, because more convenient instruments, operating upon the same principle, have been invented.

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5. What effect may be produced by two metals placed in the mouth?
6. Is the effect peculiar to silver and zinc?
7. Relate the experiment with two metallic plates.
8. How are the plates thus brought into opposite electrical states?
9. What were the substances called which possess this property?
10. What was Volta's reasoning on the subject, and to what did it lead.
11. How did Volta construct his pile, and what was the result?

Insulated plates of copper and zinc.

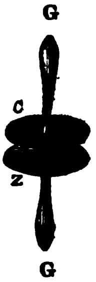


Fig. 1.

Voltaic Pile.

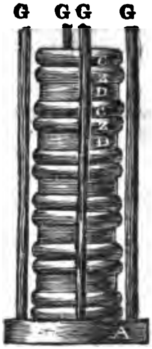
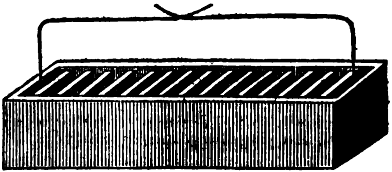


Fig. 2.

[Fig. 1. Z, a plate of zinc. C, a plate of copper, each plate being furnished with a glass handle, G, G, to preserve their electricity after contact.
Fig. 2. A, the stand upon which the plates rest. C Z D, C Z D, plates of copper and zinc, and disks of moistened cloth piled alternately upon each other. G, G, G, G, rods of glass to support the pile.]

Caroline. The trough that you have upon your table I have heard you call the voltaic battery, and I suppose it is to this which you allude as being more convenient than the pile.

Voltaic Battery.



[A trough with partitions, each formed of a plate of copper and zinc.]

Mrs B. It is. A wooden trough is made, and this is divided into cells by metallic partitions, which are cemented firmly into grooves made in the trough. The metallic partitions are each formed by soldering together, back to back, a sheet of copper and a sheet of zinc. When these are cemented into the trough, the copper sides are all made to face one way. The cells between the plates are to be nearly filled with water, having some nitric, or other acid, mixed with it(12). The resemblance between these troughs and the pile must be obvious to you.

Emily. Certainly. The zinc and copper are the same, excepting that they are soldered together. The fluid between them evidently supplies the place of the moistened cloth; and the two plates at the ends will, I suppose, be in opposite electrical states, as you have told us is the case with the pile(13).

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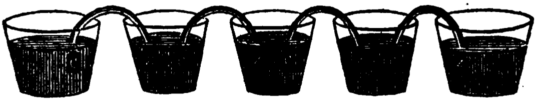
12. Can you describe the voltaic trough, or battery?
13. In what way may this be compared with the pile?

Mrs B. Very good. I will now show you another arrangement, made by Volta, which he described in the same paper in which he made his pile known. A number of cups, or glasses, are placed side by side, each of them containing the fluid intended to promote the electric action. These cups are connected by metallic wires bent in the way you see, and having a small plate of zinc soldered on one end, and a plate of copper on the other. If you observe how the plates are placed in the liquid, you will see that each cup, excepting those at the ends, has one plate of zinc and one of copper immersed in it, in regular series. If you dip a finger of each hand into the extreme cups, a shock will be received. This arrangement Volta denominated the *Couronne des Tasses*(14).

Couronne des Tasses.

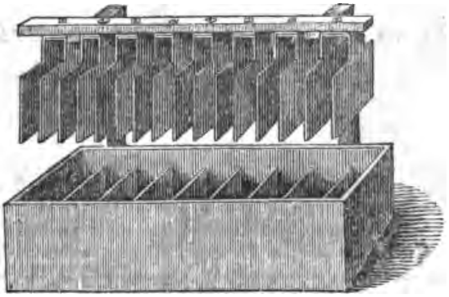


C, plates of copper. Z, plates of zinc.

Caroline. How pungent the sensation, yet I do not think it half so unpleasant as one of equal strength from the electrifying machine. I do not see why the name of *couronne* was given to this arrangement.

Mrs B. When the cups are numerous, in order to bring the two end ones near to each other, they are usually so placed as to form a circle; it was this arrangement which suggested the name(15). There is another very convenient mode of constructing the trough, or battery, as it is frequently called, which has many advantages, and which you will perceive strongly resembles the *couronne des tasses.* The trough is made of earthenware, divided into cells by partitions of the same material. The plates of copper and zinc are connected together by a strip of metal at the top only; so that both sides of each plate may be exposed to the action of the acid. The pairs of plates set like saddles upon the earthen divisions, the copper being in one cell, and the zinc in another. All the plates belonging to one trough may be fastened to a strip of wood, by which they may readily be taken out of the solution contained in the cells, and the action of the acid be consequently suspended until they are replaced. There is, as you see, in this trough a contrivance for hanging the plates over it(16).

Voltaic Battery, the Trough of Earthenware, with the Plates out of the Cells.



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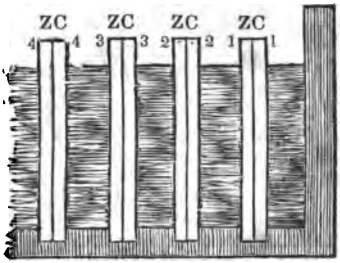
14. Describe the arrangement called the *couronne des tasses.*
15. Why did this apparatus receive the name of *couronne?*
16. Describe the trough which resembles the *couronne des tasses.*

Emily. The arrangement in each case is manifestly similar; but how the *electro-motive* power operates through the plates in producing the opposite electricities, is what I do not understand, and hope you will explain.

Mrs B. You must keep in mind what we have said upon the subject of theory, and expect but little in this way. Volta attributed the whole effect to the electro-motive power of the metals; but it is found that when the fluid used contains an acid which will corrode and dissolve one of the metals, the power is very greatly increased. It appears, therefore, that in this case a large portion of the effect results from chemical action(17).

This drawing shows a section of a part of the trough, the construction being of the kind first described, and this will serve to give you a general idea of Volta's theory of its action. Z C, Z C, &c. represent pairs of copper and zinc plates, with the fluid between them. A portion of the trough is seen at the bottom and at one end.

Section of the Voltaic battery.



Volta's theory of the action of a number of pairs, is merely an extension of the action of a single pair. The zinc plate 1, being in contact with the copper plate 1, will deprive the latter of a portion of its electricity, and will become positively electrified. The same action must evidently take place in each of the other pairs, 2 2, 3 3, and 4 4. The interposed fluid, which is an imperfect conductor, will transmit from the positive zinc plate 1, a portion of its excess to the negative copper plate 2, which had already given a part of its own to the zinc plate 2. This will then, from the electromotive power, afford an increased portion to the zinc plate 2, the electrical state of which will be proportionally exalted. The same reasoning will apply to the plates 3 3 and 4 4, so that the electrical energy will increase with the number in the series(18).

Caroline. The explanation, upon the whole, seems to me clear, but I do not see why the electro-motive effect of the subsequent series should be greater than that of the first pair, as it is an innate power in each, and arises from the tendency in the copper to give a part of its natural share to the zinc. That each must thus become electrified is plain, but I should have anticipated that they would be so in an equal degree(19).

Mrs B. The terms negative and positive, to borrow a simile again from caloric, may be considered, like those of hot and cold, to be relative only. A body at a given temperature may be hot when compared with one body, but cold when compared with another. Suppose a plate of copper to have an excess of electricity communicated to it, and to be brought into contact with a plate of zinc, then, from the tendency of this fluid to an equilibrium, one half of the excess would go over to the zinc; but the electro-motive power of the metals remaining unchanged, another portion would be communicated to the zinc from this cause(20).

Emily. It would seem in this case as though a constant current of the fluid would be kept up as long as the instrument lasted, as this electromotive power must always continue the same.

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17. What is necessary to a powerful effect?
18. How, according to Volta, is the electricity accumulated?
19. What objection does Caroline urge to the theory?
20. By what reasoning is this objection obviated?

Mrs B. If wires be made to connect the negative and positive ends, generally called the *poles* of the battery, a constant current will be kept up; but if this connexion be interrupted, the plates acquire a certain degree of electricity, and then the action must necessarily cease(21). You must not suppose, however, that under any circumstances this action would be perpetual. It is a fact that immediately after a pile is put together, or the fluid supplied to the cells of a trough, the action is the most energetic; but it soon perceptibly diminishes, and at length becomes extremely feeble, or altogether extinct(22).

Caroline. But that does not accord with the *theory*.

Mrs B. It accords, however, with the *fact*, and you have not already forgotten to which of these the greatest importance is to be attached? I have informed you that to obtain energetic action, a fluid must be used which will corrode and dissolve one of the metals; and the power of the trough depends in a great degree upon the strength of this chemical action. The theory of Volta is therefore defective, inasmuch as it takes no account of this circumstance(23). As you are not yet acquainted with the nature and action of the acids, and of the other agents employed, the information which I can give you at present must be very limited; but, as the voltaic battery is a most powerful instrument in effecting decompositions, we shall have occasion to revert to it hereafter, more, however, with a view to exhibit its actual power, than to theorize upon its nature.

Emily. If an acid is used and the metal is dissolved, the apparatus itself must at last disappear, and the copper and zinc both be lost.

Mrs B. Recollect that an acid, if it has an affinity for several different metals, possesses it for them in different degrees; and that, in consequence, one may be made to displace another which is held in solution. If two metals, either of which would be dissolved in an acid if put into it alone, be placed there together, it will act upon that to which it has the strongest affinity, whilst the other will remain nearly unaffected(24). The acids generally have a much stronger affinity for zinc than for copper, and the zinc plates of the voltaic trough are consequently made thick, or they would soon require renewal(25).

Emily. Certainly if the zinc would separate the copper after it had been dissolved, it may well have the power to prevent its solution. This appears a necessary result, although I do not pretend to know any thing of the cause.

Caroline. I think, Mrs B., as this kind of chemical action which takes place between acids and metals, is so intimately connected with that of the voltaic battery, you might, perhaps, by your happy mode of explanation, enable us so far to comprehend it as to aid us in the present inquiry.

Mrs B. This I intended, and your anxiety upon the subject is a fair omen of success. We have only to anticipate a part of the subject of our next conversation, which will embrace *oxygen*, a principle entering into the composition of the greater number of bodies. The air we breathe contains oxygen, and derives from it the property of sustaining life and supporting combustion. It is one of the constituents of water, of which it forms eight parts out of nine. It is the principle which communicates to most of the acids their sour taste, and their other general properties. It is that which in a damp place unites to iron or steel, and converts it into rust, or what the

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21. In what way is a continued current maintained in the battery?
22. Will the action continue undiminished?
23. In what point is the theory of Volta defective?
24. What will follow if two different metals be put into the same acid?
25. What reason is there for making the zinc plates thicker than the copper?

chemist denominates the *oxide* of iron; and in like manner it may be made to unite with all the metals, to some of which, as to iron, it has a very strong affinity, whilst for others its attraction is feeble. In fact the enumeration of its habitudes would almost exhaust the subject of chemistry(26).

Emily. I have long been familiar with the name, and had some vague idea of the nature of this same oxygen, and am glad that we are so soon to be introduced to a personage so extensively connected; but I am very apprehensive that I shall never become familiar with all his relations.

Mrs B. When a metal is dissolved by an acid, it is first converted into an oxide, and it is this oxide which undergoes solution(27). The oxygen is derived in some cases from the acid, and in others from the water with which the acid is mixed. A solution of zinc in an acid is, therefore, strictly speaking, a solution of the oxide of zinc, and a solution of copper, a solution of the oxide of that metal(28).

Copper and zinc are uniformly employed for galvanic arrangements, because there are no two metals equally energetic and cheap; but various other combinations will answer the purpose, and in all cases it is the most oxidizable of the metals which forms the positive pole of the series. Thus when copper and zinc are used, the zinc becomes positive, and the copper negative; but with silver and copper, the latter would form the positive pole(29).

Caroline. Since such important changes are taking place both in the fluid and in the metal, I can very well believe that they must powerfully influence the electrical action which results from the electro-motive power.

Mrs B. The late eminent Dr Wollaston was of opinion that the evolution of electricity was caused entirely by the chemical action, urging in support of it the fact that they were proportionate to each other. When water alone is used in the cells, the zinc is slightly and slowly oxidized, and a very minute portion of electricity is disengaged. When salt and water are employed, the oxidation and the electricity are both increased; and when acids are employed, the development of the fluid keeps pace with the rapidity of the oxidation(30). This theory, you perceive, neglects the electromotive power of the metals altogether, which, as it does exist, seems to claim a place in the account(31). Sir Humphry Davy thought that the excitement was commenced in the electro-motion, but was continued and augmented by the chemical action(32).

Oxygen and certain analogous substances are always attracted towards the positive pole of a battery. They are therefore called *electro-negative* bodies, as their natural electrical state in their relationship to other bodies is believed to be negative, and they are therefore attracted by such as are *electro-positive*. The *electro-positive* bodies are distinguished by their being attracted towards the negative pole of the voltaic battery. This latter is a very large class, including all the metals, and those substances usually called inflammables(33). These are very important distinctions, and are frequently adopted as the foundation of chemical classification(34).

Emily. Then I suppose the oxygen, which is negative, is attracted by

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26. What is said of the combinations of oxygen?
27. What combines with a metal in order to its being dissolved by an acid?
28. How does it obtain this oxygen, and what is said of certain solutions?
29. What is it that determines the positive and negative poles?
30. What was Dr Wollaston's opinion respecting the chemical action?
31. This theory neglects an important fact, what is that?
32. What did Sir Humphry Davy suggest on this subject?
33. How are bodies denominated, as regards electric attractions?
34. What is said of these distinctions?

the zinc, which is positive, and that this is a principal cause of their combination(35)?

Mrs B. This appears to be intimately concerned in their union; and without admitting the suggestion of Sir Humphry Davy, that the difference in the electrical states is the cause of chemical affinity, it is plain that it exerts a powerful influence.

The theory of Sir Humphry Davy supposes that the primary action of the series depends upon the electro-motive power by which the plates are reciprocally rendered positive and negative, and that the effect of the chemical action is to restore the plates to the natural state, so that they may reproduce a fresh portion of the fluid by their electro-motive power. Suppose the acid in the solution to be a compound of oxygen, which is *electro-negative*, with a base which is *electro-positive*, the oxygen will combine with the zinc, which has been rendered positive, and thus restore it to its natural state; whilst at the same time the other constituent of the acid which is *electro-positive* will be attracted by the copper, and restore it also to the natural state. A new portion of the electric fluid will then be produced by the action of the metals upon each other. I have been compelled to describe these effects as taking place alternately, but you will understand that they must be simultaneous(36).

Caroline. Although there is a good deal of intricacy in all this, I think that with a little reflection I shall understand it; and, at all events, I like it because it seems to do justice to Volta, as it still leaves his theory whole, and only makes some addition to it. I confess that I like better to hear the pile and the trough called voltaic than galvanic; for whatever might be the merit of Galvani, Volta was the true discoverer of the nature of the agent, as well as of the apparatus by which it is exhibited.

Mrs B. I have thought it right to give you these ingenious speculations, which, as they proceeded from individuals who were luminaries in science, are well worthy of our attention, and are calculated to gratify a laudable curiosity.

Emily. Although there is certainly considerable analogy between galvanism and electricity, they yet seem so different in several points as to leave some doubts of their identity. In damp weather the electrifying machine will not act, as you have often told us, because the moisture conducts off the fluid; yet your trough is filled with moisture in order to excite it into action.

Mrs B. There are so many strong proofs of the identity of the two as to leave no doubt upon the subject. A shock very similar to that from the common electrifying machine is given by the voltaic arrangement. The same substances which conduct the one, allow a passage to the other. A number of individuals by joining hands will simultaneously receive the shock from either. Brilliant sparks are afforded from each, accompanied by a snapping noise. They produce combustion in the same articles. By proper management they effect similar chemical changes. The resulting attractions and repulsions are alike; and a common Leyden jar may be charged by the voltaic battery, the charge being exactly similar to that from the common machine(37).

Caroline. This is indeed a formidable list of resemblances, and the evidence it affords is irresistible; still, as Emily says, it seems strange that the

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35. What influence has this on the zinc plates?

36. What are the prominent points in Davy's theory?

37. What proofs are given of the identity of the galvanic and electric fluids?

action continues in the midst of water and metals, which are good conductors(38).

Mrs B. The electric fluid, like caloric, appears to exist under different modifications. Caloric you know passes slowly along conductors, but moves with immense velocity when radiating from the sun, or from heated bodies. The solar heat passes readily through glass, whilst that from our fires is arrested by it, its projectile force appearing to be less in the latter case than in the former. The electric fluid in like manner possesses but little projectile force, or intensity, though disengaged in large quantity by the voltaic apparatus. Water and most other fluids are but imperfect conductors of electricity, and may detain it therefore when its intensity is but small; although they will conduct it off from the common machine, whence it has a great disposition to escape. In consequence of this want of intensity, the spark from a powerful voltaic battery will strike at a very small distance only; and it becomes necessary to moisten the hands in order to take a shock, it not having sufficient force to overcome the resistance of the dry skin(39).

Emily. You have told us that the strength of the shock is in proportion to the number of plates; but have said nothing respecting their size. As you enlarge them the quantity of the fluid must of course be increased.

Mrs B. It is a remarkable fact, that although the quantity of the fluid is increased by enlarging the plates, yet the power of the shock remains the same(40). This increased quantity however produces most brilliant combustions of the metals, and of other inflammables(41). By increased numbers the intensity is increased, and upon this the force of the shock depends; but in burning the metals, what is principally required is a large quantity, and as they are good conductors, the fluid will pass through them, although its intensity may be very low(42).

From the fact that when the plates are large in size and few in number, the electrical effect is feeble, and the calorific, or heating, strong, and that when the number is great, and their dimensions small, the reverse is the case, Dr Hare of Philadelphia has drawn the conclusion that the galvanic fluid is a compound of electricity and caloric, and that one or the other power prevails according to the nature of the apparatus employed. He has given to the science some powerful instruments, particularly one which he denominates the *calori-motor*, intended to exemplify the justness of his conclusions(43).

Caroline. In what way has the voltaic battery so powerfully aided the chemist in overcoming chemical attraction, and consequently effecting decompositions?

Mrs B. It appears that there is as general a difference in the electrical state of bodies as there is in their capacities for caloric; that in compounds, therefore, the bodies which are combined are negative and positive in their relationship to each other, and that they will consequently be attracted towards the opposite poles of the battery. This attraction may be made more powerful than chemical affinity, and hence it follows that when a compound is placed in the electric circuit, its constituents will be separated, one portion going over to the negative, and the other to the positive pole(44). The particular manner of proceeding will hereafter be shown to you; but we

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38. What circumstance seems to militate against this identity?
39. What is urged in reply to this objection?
40. Is the shock increased by enlarging the plates?
41. What effect is produced by such enlargement?
42. What reason is given for this increased power of combustion?
43. What is Dr Hare's theory, and what instrument has he invented?
44. How does the voltaic battery overcome affinity?

must wait until we arrive at the substances to be acted upon, in the regular progress of our studies.

I might describe to you several modes of constructing the voltaic battery, but must leave them as objects of inquiry for yourselves hereafter. I shall not however dismiss the subject without some notice of the remarkable discoveries which have been recently made respecting the intimate connexion which exists between electricity, heat, and magnetism,—discoveries which go far towards justifying the opinion that they, and probable light also, are all modifications of the same etherial matter, and have even been thought to promise some insight into the nature of the planetary motions themselves(45).

Caroline. That will be delightful. We may then make little worlds, and set them revolving round each other. I am impatient until I know how this may be done.

Mrs B. I hope, my dear, that your impatience may not continue until you acquire this information, or I fear that it will be permanent. This is a mere speculation of some warmly imaginative philosophers, who have related their waking dreams. At present I can only narrate a few facts to you, and exhibit two or three very curious experiments, with respect to which I have not a word of theory to offer, and shall make no conjectures. It is a subject which engages the attention of the most scientific men, from whose united labours important discoveries may be reasonably expected.

Emily. Then we must be content to be observers only, and not inquirers. I will endeavour to play my part well; what say you Caroline?

Caroline. I well know that I shall find it necessary to use the curb, and shall very willingly put it on. The lessons which I have received have not been entirely lost upon me; for although I like as well as ever to learn how certain effects are produced, I perceive most plainly that all valuable information of this kind must be derived from observing and comparing together a great number of facts. It would be extremely unreasonable, therefore, to expect a satisfactory theory respecting any new phenomenon before time has been allowed to investigate it thoroughly. The world had existed for thousands of years, and the effects of gravitation had been witnessed by every one, yet the discovery of it, as pervading the universe, was reserved for Newton.

Mrs B. The name of *Electro-Magnetism* has been given to this new branch of inquiry. The terms *thermo-magnetism* and *thermo-electricity* are also applied to some of the phenomena, according to the powers which appear to be principally engaged in or developed by them(46).

When the poles of a voltaic battery are connected by a wire extending from one to the other, an uninterrupted current of the fluid passes through it. If a magnetic needle be placed near this connecting wire, it will be made to deviate from its natural position, and to point in various directions, according to the mode of conducting the experiment; thus it may be made to point *east* and *west*, instead of north and south. The connecting wire is one of platinum, a metal not oxidized by the electric current, nor, under ordinary circumstances, affected by the magnet(47). After this apparent attraction had been discovered, it was soon ascertained that the action of the connecting wire upon the magnet was not owing to a mere attraction existing between them, but to a tendency which they have to revolve round each other(48).

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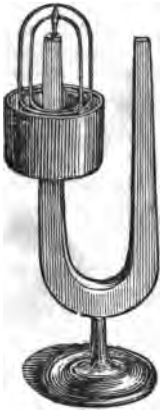
45. What is said respecting the imponderable agents?
46. What new terms are employed to designate their action?
47. What peculiar action exists between the voltaic battery and a magnet?
48. What is the tendency of the magnet and of the wire?

Caroline. I think, Mrs B., that the accounts which have appeared of the magnetism of a compass-needle on board a ship having been reversed by a stroke of lightning, show that there is an intimate connexion between these two powers.

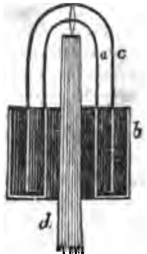
Mrs B. There are several such accounts. Needles have had their poles reversed, their magnetism sometimes destroyed, and at others communicated by lightning, and the same has been done both by common and voltaic electricity(49).

This little instrument will exhibit the rotatory motion of a wire round the pole of a magnet. A cup is made of two cylinders of sheet copper; the outer one about two inches in diameter, and the inner about one inch. These have a bottom by which they are connected together, but which does not cross the inner cylinder, that being open below as well as above. This forms a cup for containing a diluted acid between the two cylinders. To the inner cylinder a copper wire is soldered, which forms a bail connecting the opposite sides. From the centre of this bail a point projects downwards, upon which it can freely turn upon one of the poles of a strong magnet. A second cylinder or tube of sheet zinc, about one inch and a half in diameter, and left open at both ends, is suspended by a similar bail, as you see; its point resting in a small hollow in the first wire. This cylinder of zinc hangs within the copper cup without touching it, and with the surrounding copper, and the contained fluid forms a galvanic arrangement. The cups being suspended upon fine points, revolve with but little friction(50).

Instrument for Electro-magnetic rotation.



Section of the Electro-magnetic instrument.



[*c*, wire supporting the tube of zinc. *b*, the copper vessel, supported by the wire *a*. *d*, the magnet passing through the inner cylinder of the copper vessel.]

Emily. Astonishing! they both begin to revolve, but turn in reversed directions. I do not wonder that a fact so extraordinary should for awhile puzzle the philosophers. But would not the cups revolve without the magnet, by the galvanic influence merely?

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49. How has this magnetism of a needle been reversed or destroyed?
50. Can you describe the *electro-magnetic* instrument?

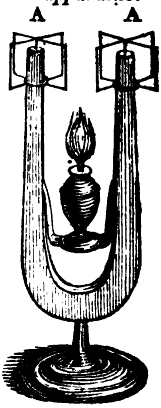
Mrs B. Not at all; it is the combined influence of the two which produces the result(51). I will now show you a similar effect without the voltaic cups, their absence being compensated by the influence of caloric. This apparatus is thence denominated *thermo-magnetic.* These little wire cages are formed in part of silver and in part of platinum; they have each a point by which I suspend them upon the ends of this horse-shoe magnet, so that one surrounds each pole.

When the spirit lamp below is lighted the cages become heated, and immediately begin to revolve, in contrary directions, and this they will continue to do as long as the lamp is allowed to burn. We have here the combined action of magnetism, heat, and electricity; the latter being undoubtedly developed by the action of the compound metallic cages.

Caroline. I must not ask any thing about causes, and I am sure that I cannot tell any thing about them; but certainly this does appear like a peep behind the curtain which conceals the grand arcana of nature, and I hope to live long enough to obtain a more perfect view(52).

Mrs B. We shall at our next conversation proceed to the consideration of more tangible materials, and to matters less abstruse than those which we have had upon the tapis to day. I have said more upon the subject of electricity than I at first intended; but it has become so completely interwoven with the phenomena of chemistry, that we can scarcely stir a step without its aid, as we witness its influence in almost every chemical change, whether natural or artificial.

Thermo-magnetic apparatus.



[A, A, wire cages of platinum and silver, which revolve in opposite directions upon the two poles of the magnet when the lamp is lighted.]

CONVERSATION X.

ON ATMOSPHERIC AIR, OXYGEN, NITROGEN, OR AZOTE, AND COMBUSTION.

Constitution of Atmospheric Air. Simple Gases. Vapours. Distinctive Properties of Oxygen and Nitrogen. Combustion of a Candle in Atmospheric Air. Lavoisierian Theory of Combustion. Its defects. Fixed and Volatile Products. Oxygen discovered by Priestley. How obtained. Pneumatic Cistern.

Mrs B. To day we shall examine the chemical properties of the atmosphere, and of the two simple gases of which it is composed.

Emily. I always thought that the atmosphere was a very complicated fluid, composed of all the variety of exhalations from the earth.

Mrs B. These various exhalations are contained in the atmosphere, but must be considered as accidental mixtures, like the heterogeneous substances dissolved in water, which fluid we never find in a state of absolute purity.

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51. How do the cups revolve, and what proves the action of two powers?
52. Will you describe the *thermo-magnetic* apparatus?

The essential ingredients of the atmosphere are OXYGEN GAS and NITROGEN GAS, or *azote*(1).

Emily. Pray tell me in what respect *air* and *gas* differ from each other?

Mrs B. Strictly speaking they are synonymous terms, but in common language when we speak of air we mean the atmosphere, no other species of air having been formerly known. When the airs were found to be numerous, the term *gas* was adopted as a generic one. Any fluid which remains permanently elastic under atmospheric pressure, at every natural temperature, is called a gas(2). *Oxygen*, *nitrogen*, and some others are sometimes called simple gases, because they contain but one *base*, there being some gases which have two or more *bases*(3).

Caroline. I do not understand this acceptation of the term *base*. If a gas is simple, it must consist of one material only.

Mrs B. *By a base we mean the principal ponderable material which enters into the composition of a body, and upon which its characteristic properties depend*(4). The term gas at once indicates the presence of caloric, as necessarily as do the words steam and vapour. Oxygen gas is a combination of oxygen with caloric, and nitrogen gas of nitrogen and caloric. Oxygen is the base in one case, and nitrogen in the other(5).

Emily. Then the only difference between a vapour and a gas would appear to be the temperature at which they are converted into liquids or into solids(6).

Mrs B. Precisely so, and many of them have actually been rendered liquid by the united influence of cold and of great mechanical pressure. It appears perfectly fair, therefore, to consider the gases as being the vapours of liquids which are so volatile that their boiling point under atmospheric pressure is lower than any natural temperature(7). You must therefore never expect to see the bases of these gases in their simple state; for when disengaged from any solid in which they are combined, they instantaneously become gases; because there is no natural reduction of temperature at which they do not find caloric enough to convert them into that form(8).

Caroline. In what proportions are the two gases contained in the atmosphere?

Mrs B. The oxygen gas is generally estimated at a little more than one fifth. One hundred parts by measure of atmospheric air have been said to contain twenty-one measures of oxygen and seventy-nine of nitrogen. Some eminent chemists, however, think that twenty of the one to eighty of the other may safely be set down as the true proportions(9).

When separated from each other, as you have already been informed, their qualities are found to be totally different. The nitrogen will not support combustion or animal life, whilst in the oxygen every combustible burns with greatly increased splendor and rapidity. Animals also will live longer in a confined portion of it than in the same bulk of atmospheric air, and for a time, appear to experience a pleasant stimulus(10)

Caroline. What a pity that there should be but one-fifth of oxygen in

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1. Of what does the air of the atmosphere consist?
2. What do we intend by the terms *air* and *gas?*
3. When are airs or gases denominated simple?
4. What is meant by the term *base?*
5. What does the term gas indicate, and what are its examples?
6. In what do vapours and gases differ from each other?
7. What proof is adduced of the analogy between them?
8. What is the difficulty in procuring the bases of the gases?
9. In what proportion are the two gases contained in the atmosphere?
10. How are oxygen and nitrogen distinguished when separate?

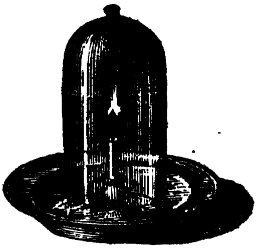
the air. If the proportion was greater our candles would give more light, our fires more heat, and we should probably breathe more freely, and live more merrily than we now do. If the nitrogen neither supports life nor combustion, I do not see its use.

Mrs B. And probably you never will know one-half of its uses. But He who formed the atmosphere, has in infinite wisdom adapted it to the perfect fulfilment of his beneficent designs. In pure oxygen your candle would disappear in a minute or two, and even your iron candlesticks would take fire and burn up; and it would be just as rational to desire our rivers and springs to flow with brandy, as to wish for an atmosphere of pure oxygen, the stimulating effects of which would rapidly destroy life(11).

That the nitrogen contained in the atmosphere is as necessary to living animals as the oxygen, will appear plain to you, when I inform you that it has been ascertained that their well-being not only depends upon its presence, but upon its being present in the exact proportion in which we find it(12).

Emily. And by what means can the two gases which compose the atmosphere be separated, so that we may examine their properties.

Candle burnt in atmospheric air under a receiver.



Mrs B. There are many ways of effecting their separation, and of obtaining the nitrogen gas, but we know of no process by which to separate the nitrogen and leave the oxygen in the gaseous form(13). A burning body placed in a confined portion of atmospheric air will cause its decomposition. I place this lighted candle under a bell glass, the bottom of which stands in water; it immediately burns dimly, and is now extinguished. The larger portion of the oxygen has disappeared, and a second candle placed in the air which remains, would go out instantaneously. A portion of the water you see rises into the glass: this is in consequence of the absorption of the oxygen leaving a void space, and the pressure of the atmosphere forcing the water up to occupy it(14).

Caroline. How surprising that a burning candle should decompose the atmosphere and absorb its oxygen. The water I suppose will rise so as to occupy one-fifth of the contents of the glass.

Mrs B. Not so; the whole of the oxygen is not separated, although there is too little left to support combustion; and besides this there is another gas, produced in the burning, which occupies a part of the space formerly filled by the oxygen(15). There are, however, some combustibles which will unite to the whole of the oxygen and convert it into the solid form: the nitrogen will in this case be left in a state of purity. That the atmosphere should be decomposed by combustion is no more wonderful than that the candle should be so also. The tallow which disappears must combine with something, and in the present instance that something is oxygen(16).

Emily. Although I knew that air was necessary to combustion, I never

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11. What would take place in an atmosphere of pure oxygen?
12. What other fact evinces the use of the nitrogen?
13. Can the two gases be separated, so as to obtain either at pleasure?
14. How may the oxygen be separated by means of a candle?
15. Why will not the nitrogen be left pure?
16. What remarks are made respecting this decomposition?

had an idea of the importance of its agency until now, but it is evidently as necessary to the process as the fuel itself.

Mrs B. We are indebted to that eminent French chemist Lavoisier and his associates for what is called the modern theory of chemistry, and also for the *nomenclature*, or system of names, which is now employed by chemists(17). Lavoisier's theory of combustion was also generally adopted, and deemed satisfactory. It taught that *combustion consisted in the rapid combination of oxygen with a combustible body, and the consequent disengagement of heat and light*(18).

Caroline. How simple, and how beautiful! How perfectly it accords with what we have seen! But pray whence do the light and heat come?

Mrs B. That is a question which in some instances may be satisfactorily answered, but there are others in which the theory fails in accounting for the production of heat; and therefore, notwithstanding its *simplicity* and its *beauty*, it is, like most other theories, imperfect(19).

It has been believed that light is a constituent both of gaseous and of combustible bodies, and that, in their combination, a portion of it is given out. Caloric, also, is a constituent of gaseous bodies, and consequently of oxygen, and has been supposed to supply the heat which is disengaged in combustion(20). Oxygen frequently combines with the combustible and passes into the solid or liquid state, and of course gives out the caloric which converted it into a gas(21). At other times it combines with the combustible and forms with it a compound gas, the capacity of which for caloric is less than that of oxygen, and, of course, latent heat will then be rendered sensible; and that in a degree proportioned to this difference of capacity(22).

Caroline. But this would be to suppose that the heat came from the air and not from the fuel, which seems contrary to our experience.

Mrs B. Recollect, my dear, that our conversations need not be continued, if your senses alone are to be your guides. In the slaking of lime you now believe that the heat disengaged is derived from the water; and when you are convinced that oxygen gas is as necessary, and as actively engaged in the process of combustion as the fuel itself, you must be compelled to attribute to it a full share in producing the effect, although it is itself invisible.

The combination takes place only at the surface of the burning body, where the air has free access to it(23).

Emily. What are the principal objections to the Lavoisierian theory of combustion?

Mrs B. At the time the theory was proposed, oxygen was the only known supporter of combustion, but there are other agents which are now admitted into the class: these are *chlorine*, *iodine*, and perhaps *bromine*. Although combustion does, in general, consist in the rapid combination of oxygen with a combustible body, this is not universally the case(24).

There are also many chemical combinations which are accompanied by the disengagement of light and heat, where neither of these *supporters*, as they have been called, are present(25). In many instances of combustion we

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17. Who were the authors of the modern theory and nomenclature?
18. What definition did Lavoisier give of combustion?
19. Why is this theory accounted imperfect?
20. Whence have the light and heat been supposed to be derived?
21. What change in the oxygen may cause it to give out heat?
22. When the product is a gas, whence may the heat be derived?
23. What observations are made respecting oxygen being the source of heat?
24. What objections exist against the theory of Lavoisier?
25. What further objection is stated?

are not acquainted with the source of the heat, as in the firing of gunpowder, and other explosive mixtures. In these, solids are converted into gases, and this, according to the Lavoiserian theory, should produce cold, as an increased capacity for caloric is the necessary result of such a change(26). It is now, therefore, the practice among chemists to state, in general terms, that *combustion is the result of energetic chemical action*(27).

In our present conversation, when speaking of combustion, you are to understand me as intending the burning of bodies in atmospheric air, oxygen gas, or some gas containing oxygen; and the *products of combustion* as consisting of a combination of oxygen with the combustible body(28). The exceptions we shall place by themselves, as they are instances of combustion with which you are not familiar.

Emily. By the *products of combustion*, I suppose you mean the smoke and ashes, or other substances which are left after a body has been burned.

Mrs B. This would be not only a very meagre, but a very incorrect definition. In the greater number of instances the products of combustion exist in the gaseous form, and are from this cause invisible; they are then called *volatile products*. When they remain in the solid state, they are called *fixed products*(29). The whole of the tallow of our candles, and of the oil of our lamps, and a large proportion of our wood and coals form, with the oxygen, volatile products, which, if collected and weighed, will be found to contain all the matter that has apparently vanished, not an atom being lost(30). Smoke is not properly a product of combustion, as it consists principally of a part of the fuel which escapes combustion, and which, by its condensation, forms the soot in our chimneys(31).

When the products of combustion are altogether of the kind called fixed, it is easy to show that, in burning, they have acquired weight, instead of suffering a diminution.

Emily. That is very extraordinary; for although the light and heat which have escaped may weigh nothing, and the body may not sensibly lose weight, it is strange that it should become heavier.

Caroline. It has just occurred to me how this may be; you know that the air possesses weight, and if the oxygen gas unites with the combustible, the two together must weigh more than the one(32).

Mrs B. You have given the correct explanation, and yet have made one mistake: the oxygen, which is the *base* of the oxygen gas, combines with the combustible, assumes the solid form, and loses its existence as a gas. You must carefully distinguish between a gas and its base, or your ideas upon this subject, like those of many others, will be frequently confused(33).

Caroline. Combustibles, I know, are bodies which may be burned; products of combustion I understand to be those which have been burned; but there are many which do not belong to either of these classes, such as rocks, earths, metals, and, I think, a great many others(34).

Mrs B. A little time will teach you that the bodies which you have named are either combustibles, or products of combustion. Rocks and

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26. How does the firing of gunpowder, &c. militate against it?
27. What more general definition may be given of combustion?
28. How are we at present to limit the remarks on this process?
29. How are the products of combustion divided, and why?
30. What is said of the products from tallow, oil, coals, &c.?
31. Is smoke, properly speaking, a product of combustion?
32. What do we find the fixed products to have acquired, and why?
33. Does the *gas* combine with the combustible body?
34. What does Caroline remark respecting combustible products, &c.?

earths are generally compounds of a combustible body with oxygen, and the metals are all combustible, notwithstanding some of them require a most intense heat to cause them to burn. Some bodies, you know, take fire at a much lower temperature than others(35).

Emily. But are there not some combustibles which have so strong an attraction for oxygen, that they will rapidly combine with it without first applying heat to them?

Caroline. That cannot be, otherwise we should see such bodies taking fire and burning spontaneously.

Mrs B. There are in existence some such bodies, such as phosphorus, potassium, and others, with which you will hereafter become acquainted. These bodies, however, are all prepared by art; as, naturally, they are found combined with oxygen, from which it is necessary to separate them by chemical means. The very nature of such bodies forbids their existing in an uncombined state any where near the surface of the earth, where oxygen can have access to them(36).

Emily. Was not oxygen gas discovered by Lavoisier?

Mrs B. No, my dear, it was discovered in the year 1774 by Dr Priestley, who called it *dephlogisticated air.* It afterwards received the name of *vital air*, because it is necessary to the support of life, and Lavoisier called it OXYGEN, a name derived from two Greek words, signifying *acid*, and *to generate;* because it was found that many combustibles in their combination with oxygen were converted into acids(37). Thus sulphuric acid, or oil of vitriol, is produced by the combination of oxygen with sulphur. Oxygen was believed, therefore, to be the *acidifying principle*, and it was assumed that all the acids contained it(38). We have since learned that it is not the only supporter of combustion, and have also discovered that some acids exist which do not contain it(39).

Caroline. I long now to see some of the rapid and brilliant combustions which take place in oxygen gas. Is it difficult to procure it in a state of purity?

Mrs B. It is not difficult to procure it sufficiently pure to exhibit its properties; but to obtain any chemical agent *absolutely pure* is a task rarely accomplished, and fortunately not often necessary(40). Oxygen is so feebly combined with some of the metals, that heat alone will separate it, and convert it into a gas(41). It was from *red precipitate* that Dr Priestley first obtained it. Red precipitate, or *red oxide of mercury*, as it was afterwards called, consists of oxygen united to quicksilver; and in order to separate them, it is sufficient to heat the compound, when the oxygen unites to caloric and becomes a gas, and the mercury is *reduced*, or brought back again into the state of quicksilver(42). Red lead, or *red oxide of lead*, and *black oxide of manganese*, in the former of which oxygen is combined with lead, and in the latter with a metal called manganese, give out this gas when heated to redness in a retort of iron or of earthenware(43). When this last oxide is mixed with sulphuric acid, oxygen is separated from it by a very moderate

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35. What is said of the nature of earths and stones, and of metals?
36. What kind of combustibles must we obtain by art, and why?
37. Who discovered oxygen, who so named it, and why?
38. What acid is mentioned as an example?
39. Why is it not still accounted *the* acidifying principle?
40. What is remarked respecting obtaining articles perfectly pure?
41. What is the fact respecting oxygen and certain metals?
42. From what was it first obtained, and how?
43. What substances yield oxygen gas when heated red hot?

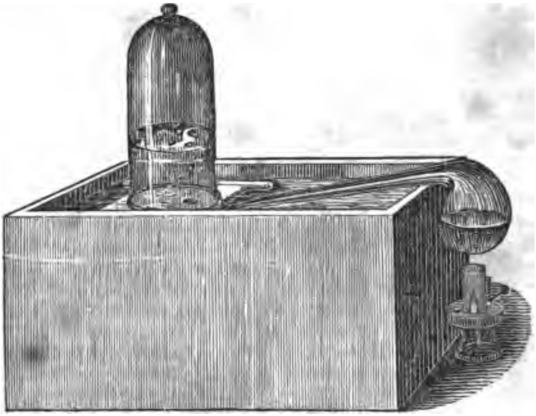
heat, as by that of a lamp(44). Common nitre, or saltpetre, also contains a large quantity of oxygen, with which it parts readily, as do some other substances; so that we have various methods of procuring it.

I have put into this retort some pulverized black oxide of manganese, and poured upon it enough sulphuric acid to form a sort of paste. The joint action of this acid, and of the heat from a lamp, will suffice to disengage a portion of the oxygen, and convert it into the gaseous state(45).

Emily. I am at a loss to know in what manner you can collect it, and keep it from mixing with common air; although I have no doubt you have some ingenious device for effecting this.

Mrs B. The means are very simple and very perfect. Before the time of Priestley, chemists knew but little of the gases. From his numerous discoveries, this philosopher has been emphatically styled the father of *pneumatic chemistry;* for although some of the gases had been distinctly noticed by others, the greater number were made known by his researches. To him also we are indebted for a most convenient mode of collecting them.

Pneumatic cistern, with a bell glass upon a shelf under water; a retort from which gas is passing into the receiver; and a lamp for heating the materials in the retort.



This vessel, which I am about to use, is called the *pneumatic* cistern, or tub. It has a shelf within it, at about two inches below its upper edge. Water is poured into it so as to cover the shelf completely. Through this shelf, holes are made for the passage of gas, the lower side around each hole being scooped out so as to form in the wood a sort of inverted funnel, to collect and conduct the gas. A receiver called a bell glass, a tumbler, phial, or other vessel is filled with water, and placed with its open mouth over one of the holes in the shelf(46). If now the beak of a retort, or a tube from any vessel from which gas is to proceed, be made to pass under the shelf, the bubbles of air will ascend through the water, and gradually displace that in the glass vessel; and as the water had excluded the atmospheric air from it,

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44. How may it be obtained at a moderate heat?
45. Describe the preparatory steps of the process.
46. Describe the *pneumatic cistern,* with a receiver placed on it.

the gas which passes up will be collected, uncontaminated by admixture with any other(47).

Caroline. How beautiful the bubbles appear in rising, and how simple and convenient is the apparatus altogether! I shall be delighted to make some experiments with it myself.

Mrs B. You can try your skill in that way at your leisure; but as you will find some experience necessary in order to manage it with address, it will be best for you to practice at first with atmospheric air, which you may pour from one inverted vessel into another, as I shall transfer into this wide mouthed phial some of the oxygen which we are now collecting. To do this I fill the phial with water, and invert it over one of the holes on the shelf; I then press the larger vessel, containing the oxygen, sufficiently deep in the water to pass its edge under the shelf, so that when I tilt it on one side, the gas which escapes from it shall be conducted into the phial. In this way gases can be poured from one vessel into another with great facility(48).

Emily. But it is an unusual kind of pouring, upwards instead of downwards: this however must necessarily result from the levity of the gas(49). Now you have filled the phial, we shall have the pleasure of seeing how brilliantly bodies burn in oxygen.

Mrs B. I have, ready prepared, a sufficient portion of the gas to perform this and other experiments illustrative of its properties, and of the nature of combustion in general. Whilst exhibiting them I shall take the opportunity of explaining such parts of the nomenclature of chemistry, as are immediately connected with the experiments. This is a subject which will claim and merit your undivided attention; and although I keep you on the tiptoe of expectation, I still think it best to postpone it until our next meeting, in attending which I need not invite you to be punctual.

CONVERSATION XI.

ON OXYGEN, SOME OF ITS COMBINATIONS, AND THE NAMES GIVEN TO THEM.

Combustion of a Candle. Of Iron Wire. Oxides and Oxidation. Acids and Alkalies. Names of Acids. Tests or Reagents. Decomposition of the Alkalies. Neutralization. Nomenclature of Oxides. Of Salts and their Bases. Designation of Combining Proportionals.

Emily. Here we are, Mrs B., waiting for you; and although we always derive light from your presence, we are sure that an unusual brilliancy will attend you in your appearance to-day. Should the light which you will diffuse prove as durable as it will be splendid, I believe that we shall never again have to complain of darkness.

Mrs B. You must take care, however, not to be so dazzled by the light of the experiments as to allow your vision to be too much dimmed to discover the truths which they are designed to place within your view. The beautiful objects in nature are, in general, best seen by the mild reflected

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47. How is the gas made to pass into such a receiver?
48. How may gases be poured from one vessel into another?
49. In what direction is the pouring, and why?

light of the sun, and the analogy will hold good in the examination of the truths of science.

Our first example of combustion in oxygen gas will be that of a taper, which, for convenience sake, I have attached to a piece of bent wire. I now light the taper and introduce it into the jar; and you perceive how much the flame is increased, both in size and brilliancy. If I blow out the taper, and immerse it again in the gas before the wick is entirely extinguished, it will burst into a flame with a slight explosion; and this you perceive I can repeat five or six times in succession(1).

Caroline. What a beautiful experiment! and how plainly it shows that an atmosphere of pure oxygen would not answer our purposes, although it might make good business for the tallow-chandlers. Our candles would burn away as fast as we could light them, and it would be of no use to blow them out, as they would be instantaneously rekindled(2).

[A taper burnt in oxygen gas.]

Mrs B. The metals I have told you are combustibles, and most of them may be made to burn very readily in oxygen. I will show you the experiment of burning iron, the combustion of which is very rapid and brilliant.

Emily. It is well that iron will not burn in atmospheric air, or I do not know of what we should make our grates and stoves.

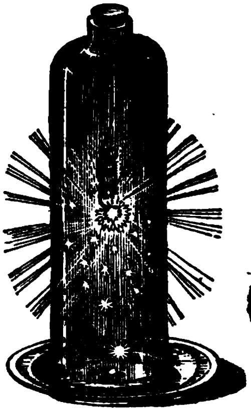
Mrs B. At a very elevated temperature, iron will burn in atmospheric air, as the blacksmith sometimes learns to his cost, when he leaves it too long in his fire. When minutely divided, it burns very readily, as you will find by dropping some iron filings into the flame of a candle(3).

The usual way of burning iron in oxygen gas is to twist a piece of piano forte wire, spirally, like a cork screw. One end of this wire is fixed into a cork which fits the top of a receiver, and around the other end a small piece of thread may be wound. This should be touched with wax, or sulphur, to ignite the wire in the first instance; as the combustion cannot commence unless the wire be red hot(4). This receiver is filled with oxygen, and, as you see, has its lower end standing in water. I will now light the piece of thread and then remove the stopper, and insert the cork in its place.

Caroline. Is there no danger of the gas escaping while you change the stoppers?

Mrs B. Oxygen gas is a little heavier than atmospheric air. It therefore will not escape very rapidly; and if I do not leave the opening uncovered, we shall lose but a very small quantity——(5).

Caroline. Oh, what a brilliant and beautiful flame!



[Combustion of iron wire in oxygen gas.]

Emily. It is almost as dazzling as the sun.—Now a piece of the

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1. How is the burning of a taper in oxygen managed, and what occurs?
2. What would be the result in an atmosphere of pure oxygen?
3. Under what circumstances will iron burn in atmospheric air?
4. How should iron wire be prepared to burn in oxygen?
5. How should it be inserted in the vessel?

melted wire drops to the bottom. I fear it is extinguished; but no, it burns again as brightly as ever.

Mrs B. It will burn till the wire is entirely consumed, provided the oxygen is not first exhausted; for you know it can burn only while there is oxygen to combine with it(6).

Caroline. I never saw a more beautiful light. My eyes can hardly bear it. How astonishing to think that all this caloric was contained in the small quantity of gas and iron which were enclosed in the receiver, and that without producing any sensible heat!

Emily. How wonderfully quick combustion goes on in pure oxygen gas! But pray, are these drops of burnt iron as heavy as the original wire?

Mrs B. They are even heavier; for the iron, in burning, has acquired exactly the weight of the oxygen which has disappeared and is now combined with it. It has become an oxide of iron(7).

Caroline. I do not know what you mean by saying that the oxygen has *disappeared*, Mrs B., for it was always invisible.

Mrs B. True, my dear, the expression was incorrect. But though you could not see the oxygen gas, I believe you had no doubt of its presence, as the effect it produced on the wire was sufficiently evident.

Caroline. Yes, indeed; and I am also convinced that in the combustion, both the oxygen and the iron have suffered decomposition.

Mrs B. You, in your turn, are not quite correct. Simple bodies cannot be decomposed. The oxygen and iron are both simple, and they have combined and formed a compound, which, were you to decompose it, would again furnish you with iron and with oxygen(8). The oxygen *gas* is decomposed, and the whole of the intense heat given out in the combustion, is probably derived from it, as its base has assumed the solid form(9). The little globules which you have seen fall down, and which are the product of this combustion, are an *oxide of iron*, and will, as we have already remarked, be found to weigh more than the iron did before its combustion.

Caroline. I wish that we had weighed the wire and the oxygen gas before the combustion; we might then have determined whether the weight of the oxide was equal to that of both.

Mrs B. You may try the experiment if you particularly wish it; but I can assure you that, if accurately performed, it never fails to show that the additional weight of the oxide is precisely equal to that of the oxygen absorbed, whether the process has been a real combustion or a simple oxidation, as we denominate the process when slowly performed, as in the rusting of iron(10).

Emily. You speak, Mrs B., of the oxidation or rusting of iron, as similar to combustion; yet in one there is a large portion of heat disengaged, and in the other none at all.

Mrs B. The processes are undoubtedly similar; and although in oxidation, from the extreme slowness of the operation, you are not sensible of the disengagement of the heat, yet there is no doubt of its actually being given out(11).

Caroline. How high the water has risen in the receiver in which the iron was burnt! much higher in proportion than when a taper was burnt in atmospheric air.

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6. How long will such a wire continue to burn?
7. What is the iron converted into, and what weight does it acquire?
8. Is this an example of the decomposition of iron and oxygen?
9. How far may it be said that decomposition was effected?
10. What is remarked on the acquisition of weight?
11. Why is not heat produced in the oxidation of iron?

Mrs B. Surely that cannot surprise you. When the taper was burnt, the whole of the nitrogen remained, and a part of the product of the combustion was gaseous. In the present instance the whole product is solid; and but for the difficulty of managing the combustion, all the oxygen gas might be made to disappear, and the receiver would, in that case, be entirely filled with water to supply the vacuum(12).

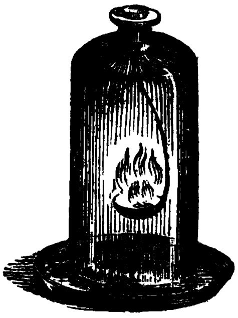
Caroline. Pray, Mrs B., in what proportion is the iron increased in weight by its combination with oxygen in combustion?

Mrs B. Its increase is nearly forty per cent; that is, every hundred grains of iron which undergo combustion combine with nearly forty grains of oxygen. The increase of weight, therefore, is not merely sensible, but very great(13). This may serve as an example of the production of an *oxide*, by combustion in oxygen gas. Some combustibles, I have told you, are converted into acids in the same way; and potash and soda, which are called alkalies, consist also of oxygen combined with a combustible. The products of combustion in oxygen are, therefore, divided into three classes,—oxides, acids, and alkalies(14). I am anxious that you should acquire some general idea of these different classes of bodies, and, for this purpose, will give you an example of each of the two last named, reserving a more particular investigation of them for our future meetings.

I have in this copper spoon some pieces of brimstone, which I heat over the candle until they begin to flame, and then immerse them in a jar of oxygen.

Caroline. Oh, what a beautiful violet coloured flame. I have often admired the flame of burning sulphur, even in atmospheric air, but then the smell is most intolerable. In the present instance it burns with increased brilliancy and without any offensive odour.

Emily. The water is now rising in the receiver as in the former combustions, proving that the oxygen has been absorbed. The vessel is entirely filled with a dense vapour(15). This, of course, must be either an oxide or an acid.


[Combustion of sulphur in oxygen gas.]

Mrs B. A very important lesson is to be learned from this experiment. The nature of a body depends not merely on the substances which unite together, but also on the relative proportions in which they have combined. There may be two or three different oxides of the same metal: thus there are two oxides of mercury, one of which contains just twice as much oxygen as the other. Several of the substances which are capable of being converted into acids, form two or more distinct acids, according as they are united to larger or smaller proportions of oxygen(16). Sulphur, when burnt in atmospheric air, becomes *sulphurous acid*, which at common temperatures is a gas. When united to a larger portion of oxygen, it becomes *sulphuric acid*, which we obtain in the liquid form under the old name of *oil of vitriol*(17).

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12. Why does the water rise to a considerable height?
13. What increase of weight does the iron experience?
14. What is said respecting three classes of products?
15. What respecting the burning of sulphur in oxygen gas?
16. What is the fact respecting the combining of bodies in different proportions?
17. How is this exemplified by the combination of sulphur and oxygen?

The vapour, or rather gas, from burning sulphur, the smell of which is so suffocating, is sulphurous acid; while sulphuric acid, although formed of the same materials, is a liquid, and entirely without odour. Now this difference results from the difference in their oxygenation(18).

Emily. I suppose that you have formed sulphuric acid by burning the sulphur in oxygen, and the vapour, which has now disappeared from the glass, was the sulphuric acid before it assumed the liquid form.

Mrs B. Not exactly so,—but little sulphuric acid is formed even when sulphur is burnt in oxygen; but sulphurous acid, though a gas when in a dry state, is, like many other gases, capable of being absorbed by water. The vapour which you saw consisted of this acid in the act of combining with the vapour of water; and this has condensed, and formed liquid sulphurous acid(19).

Caroline. I have always feared the formidable array of names in chemistry, yet I confess that hitherto I have found none of the apprehended difficulty; but I suspect that we are now entering the labyrinth, in which we shall find ourselves wofully bewildered. I think, however, that I shall remember the difference between sulphurous and sulphuric acids.

Mrs B. This formidable array of names, as you are pleased to denominate the *nomenclature*, or system by which chemical substances are designated, is one of the happiest improvements ever made in any science, and has tended more than any other single circumstance to facilitate the study of it(20). When you are introduced to a new substance, you must, of course, learn its name; but in chemistry this extends only to the simple, or elementary bodies; the compounds receiving their names from combining together those of the substances which have united. Thus oxygen and iron form oxide of iron, and oxygen and mercury, oxide of mercury(21).

Emily. But I do not see how this applies to the names of sulphurous and sulphuric acids; as we hear, in these, nothing indicating that oxygen enters into their composition.

Mrs. B. Your objection has the appearance of being a valid one, although it is not so in reality. It was thought unwise to alter known and long established names for the sake of mere system. A number of bodies possessing a sour taste, and certain other properties in common, were called acids; and when it was believed that oxygen was the acidifying principle, the name of acid sufficiently indicated its presence. It was therefore retained, and to alter it now would be extremely inconvenient, without affording any adequate advantage(22).

The acids receive their specific names from their *bases:* thus sulphurous and sulphuric acids have each of them sulphur for its base(23). The terminations in *ous*, and in *ic*, indicate that different proportions of oxygen have combined with the base, whatever that base may be. Thus, when applied to phosphorus, we have phosphor*ous*, and phosphor*ic* acids. With the sulphur contained in sulphurous acid, more oxygen may combine, and convert it into sulphuric; or we may abstract oyxgen from sulphuric acid, and thus reduce it to sulphurous(24).

Caroline. I am greatly obliged to you, Mrs B., for removing my foolish

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18. What is the difference between sulphurous and sulphuric acids?
19. What is produced when sulphur is burnt in oxygen, and what form does it assume?
20. What does Mrs B. assert of the nomenclature of chemistry?
21. How are compounds named, and what are examples?
22. What remarks are made respecting the class of acids?
23. Whence do the acids derive their specific names?
24. What do the terminations in *ous* and in *ic* indicate?

fears about names. Whilst speaking of the acids, I should like to learn some method of detecting them besides that of taste; as some of them, I know, are very acrid, and others, I believe, are poisonous.

Mrs B. Under the name of *tests*, or *reagents*, the chemist uses a variety of substances to ascertain the nature of others. Every different body has a peculiar effect upon some other body, and when such bodies are brought together, they *react* upon each other, so as to enable us to determine their natures(25). One general effect of acids is to turn the blue vegetable infusions red. I have in this wine glass a blue, or rather a purple infusion of red cabbage; a single drop of sulphuric, or of any other strong acid, will, as you see, instantaneously change it to a red. This therefore is a *test* for acids(26).

Emily. I think I have understood that the alkalies, which stand the third in your class of products, were the very reverse of the acids in their properties; yet you informed us a little while since, that they also were produced by the union of oxygen with a combustible.

Mrs B. There are a number of alkaline substances which we shall hereafter have to notice. Two of these, potash and soda, you have frequently seen, and to them therefore you will consider my present remarks as confined. They were formerly supposed to be simple, as they were undecompounded substances(27); and we are indebted to the genius of the late Sir Humphry Davy for a knowledge of their real character. The analogy between them and some other substances known to be compound, had induced him, in common with the greater number of chemists, to believe that they were actually compounds. Possessing the most extensive galvanic battery in existence, and familiar with its almost resistless power of decomposition, he submitted a portion of potash to its influence, and obtained oxygen at the positive pole, and at the negative pole a peculiar metallic substance. This metallic substance he named *potassium;* and one very similar, afterwards obtained from soda, he called sodium(28). I have in this phial a small portion of the former.

Caroline. How astonishing that potash should contain a metal! It must then be a metallic oxide, and should, I think, be so classed. But why is the potassium kept in a liquid? I should like to take it out and examine it.

Mrs B. Potash is really a metallic oxide; but still it is distinguished by the possession of those peculiar properties which belong to the substances which we denominate alkalies, and much inconvenience would result from breaking up this class of bodies(29).

Potassium is one of those substances which have so strong an affinity for oxygen that they are never to be found uncombined with it. When exposed to the atmosphere, it quickly becomes converted into potash, or rather *potassa*, as the pure article is named by chemists. The fluid which surrounds it is naphtha: this does not itself contain any oxygen, and protects the potassium from that of the atmosphere(30).

Emily. Pray will it take fire spontaneously when exposed to the air, as you have told us is the case with some articles?

Mrs B. No; its combination with oxygen is not sufficiently rapid for

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25. What is meant by *tests* or *reagents?*
26. By what test may the presence of an acid be detected?
27. What was formerly supposed respecting the alkalies, potash and soda?
28. Who decomposed the alkalies—how—and what resulted?
29. If then alkalies are oxides, why not class them as such?
30. Why is potassium kept under naphtha?

spontaneous combustion, excepting water be present, in which case it burns with great rapidity(31).

Caroline. Light a fire with water! Such a fact, I think, may add another to the number of chemical miracles. What can water contain which will promote combustion?

Mrs B. Your surprise is very natural, as you are yet uninformed of the compound nature of water. This fluid contains a large quantity of oxygen, being itself a product of combustion. The strong attraction of potassium for this substance enables it to decompose the water so rapidly as to produce combustion(32). I will now drop a small piece of the metal on the water contained in this bowl.

Emily. How rapidly and how brightly it has burnt, and how curiously it ran about upon the surface of the water! It seems to have been volatilized in the process.

Mrs B. Not so: it has formed a *fixed product of combustion*, which is now dissolved in the water, where it may be detected both by the taste and by other means. Instead of pure water, we have now a solution of potassa, with all its characteristic properties, as we can prove by the same test which we used for an acid(33). Acids caused the blue infusion to become red, but the alkali, as you see, turns it green(34); and by carefully dropping a portion of it into that which we reddened by the acid, the purple or blue colour will be restored, the alkali counteracting the effects of the acid by *neutralizing* it(35).

Emily I have not so distinct an idea as I wish of what is intended by acids and alkalies *neutralizing* each other, although this term is very familiarly used.

Mrs B. The acids are generally distinguished by a sour taste, and by reddening the blue vegetable colours; the alkalies by a peculiar acrid taste, and by changing the blue infusions to green. But in certain proportions they combine together and form a *salt*, which is neither sour nor alkaline, and which will not change the colour of the blue infusion. Such a combination is therefore denominated *neutral*, although the salt, as such, may possess very active properties(36).

Caroline. It is very extraordinary indeed that both alkalies and acids should depend upon oxygen for their formation, and yet possess properties so different.

Mrs. B. It is a striking, but not an extraordinary fact, as chemistry abounds with such examples. Properties the most contradictory result from the combination of the self same substances uniting in different proportions. Aquafortis, and the air we breathe, both consist of oxygen and nitrogen; and plants the most poisonous and the most nutritious are formed by a combination of the same simple substances(37).

You will now recollect that when bodies are burnt in oxygen gas, they are converted either into oxides, acids, or alkalies; and that it is not from an acquaintance with the simples which combine together that we could foretel what would be the nature of the product, but that we arrive at this knowledge through the medium of experiment only(38).

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31. What will cause it to take fire spontaneously?
32. How does water cause potassium to burn?
33. What is the result of the combustion?
34. How may the presence of an alkali be tested?
35. What effect will this green fluid produce on the reddened one?
36. What is meant by *neutralization*, and a *neutral salt?*
37. What is remarked respecting the effect of chemical combination?
38. What general fact is to be recollected respecting compounds?

Caroline. If the inquiry is not out of place, I should like to know how the different oxides of the same substance are distinguished from each other; as without some rule they would be confounded together.

Mrs B. Your wish could not have been better timed. The different oxides of the same substance are rarely of the same colour, and they were formerly designated from this circumstance; as the black oxide and the red oxide of iron; the red and puce coloured oxides of lead, &c.; and this method is still often used(39), although a better mode is now generally pursued. Derivatives from the Greek are employed to express the first, second, third, and highest degrees of oxygenation; as *prot*oxide, *deut*oxide, *trit*oxide, *per*oxide. When there is but one oxide known, no prefix is needed, it is merely called an oxide; when there are two, we say the protoxide and peroxide. This mode at once indicates the degree of oxidation, and has several other advantages over the plan of distinguishing the oxides by their colours only(40).

Emily. I am quite in love with this system of names, as I already feel how much it facilitates the study of the science, difficult as it at first appeared to be.

Mrs B. There is one other point in nomenclature which it will be advantageous for you immediately to learn, and that is the mode of designating the salts. This is a very large and important class of bodies, of which I can now give you only a very general idea. Salts are substances which consist of an *acid* united to a *base*(41). The alkalies, and metallic oxides, are bases with which the acids unite(42), and the name given to any salt corresponds with those of its acid and base; as sulphate of potash, which is a combination of sulphuric acid and potash; and sulphate of iron, which consists of sulphuric acid and oxide of iron(43). But sulphur*ous* acid may also unite to a base, and form a salt, which must differ from that formed by sulphur*ic* acid. When the name of the acid ends in *ous*, that of the salt terminates in *ite*; when in *ic*, it becomes *ate*. Thus sulphur*ous* acid with potash, forms sulph*ite* of potash; and sulphur*ic* acid produces sulph*ate* of potash. The same remark will apply to phosphoric and phosphorous acids, and to several others(44).

The same acid, in some instances, combines with the same base in different proportions, and this difference also requires to be designated(45). Salts were formerly divided into *neutral* salts, *super*salts, and *sub*salts. They were called neutral, when the acid and alkali were in those proportions which neutralized each other, supersalts if the acid prevailed, and subsalts if the alkali was in excess. *Sulphate of potash*, *supersulphate of potash*, and *subsulphate of potash*, might serve as examples, although, in fact, the latter is not known(46).

We now apply the Latin numerals to the salts, as the Greek are used to the oxides; employing them to distinguish the proportion which the acid and the base bear to each other, as *bis* for doubled, *ter* for tripled, and *quater* for quadrupled. Thus we say sulphate of potassa, and *bi*sulphate

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39. How have the different oxides of the same substance been distinguished?
40. How are they now most commonly distinguished?
41. What is understood by a salt?
42. What are bases with which the acids combine and form salts?
43. Give examples of the nomenclature of salts.
44. How is the state of the acid in the salt distinguished?
45. What is remarked respecting the same acid and base?
46. How were their different states distinguished from each other!

of potassa; the first consisting of a single atom, or proportional, of acid and of base, and the second, of two atoms of acid to one of base(47).

From the combination of oxalic acid and potassa in different proportions, we have oxalate of potassa, *bin*oxalate of potassa, and *quadr*oxalate of potassa; because one atom, or proportional, of the alkali is united with one of the acid in the first, with two in the second, and with four in the third salt(48).

I have now given you by far the most difficult lesson on the subject of names which you will have to learn, but am certain from your attention that you will have mastered it, or nearly so, by the time of our next meeting, when we shall take up the subject of *hydrogen*, and its combinations with oxygen.

Caroline. I certainly am not anxious to enter further into the details of nomenclature, before ruminating upon what you have already taught us; but before we part, allow me to ask why nitrogen is also called azote.

Mrs B. The term azote originated with Lavoisier and his associates. It is derived from the Greek, and signifies to destroy life; but as azote was found to be the base of nitric acid, which is obtained from nitre, chemists have generally concurred in preferring the name nitrogen to that of azote(49).

CONVERSATION XII.

ON HYDROGEN, AND ITS COMBINATIONS WITH OXYGEN.

Water a Compound Substance. Conjecture of Sir Isaac Newton. Inflammable Air. Natural Sources of Hydrogen. Formation of Water. Hydrogen always obtained from this Fluid. Processes by which Hydrogen is obtained. Used for filling Air Balloons. Proofs of its Levity. Explodes with Oxygen. Proportionate quantities of each. Discovery of the Composition of Water. Large quantity formed by the French Chemists. Musical Tones in Glass Tubes. Soap Bubbles filled with Hydrogen alone and in mixture. Some properties of Water. Deutoxide of Hydrogen.

Caroline. I feel an unusual degree of interest in the subject which is to claim our attention this morning; for although I have not the least doubt of the fact, I find some difficulty in realizing the idea that what we have so often heard called *simple* water, is a compound.

Mrs B. The compound nature of water lies at the very foundation of the modern system of chemistry, and the evidences of its truth are so numerous and so perfect, as altogether to defy scepticism(1). You cannot have forgotten the acute and extraordinary conjecture of sir Isaac Newton, which was mentioned in our *Conversations on Natural Philosophy,* that water consisted in part of a principle which was uninflammable, and in part of one which he denominated oily, unctuous, or inflammable. The conjecture of this great man has been fully verified, and presents itself to us as one of the strongest examples of the value of reasoning from analogy, when conducted with that caution which belongs to true philosophy(2).

Hydrogen gas, the base of which is one of the constituents of water, was

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47. What method is now adopted? and give examples.
48. Give the example of the combinations of *oxalic acid* with potassa.
49. What is observed respecting the names *azote and nitrogen?*
1. What remarks are made concerning the compound nature of water?
2. What respecting Sir Isaac Newton's conjecture on this subject?

formerly called *inflammable air*, as it takes fire readily and burns with flame(3). This gas, combined usually with some other inflammable, has been long known as a natural product, being disengaged in coal mines, from certain springs, and also from fissures in the ground, where it takes fire when a light is applied to it(4). When it was found to be one of the constituents of water, it received the name of hydrogen, which is derived from two Greek words signifying to produce water(5).

Emily. And how does hydrogen produce water?

Mrs B. By its combustion, in which it unites with oxygen. Water is composed of eight parts by weight of oxygen, combined with one part of hydrogen(6). If the estimation is made by the volume, or bulk, of the gases, we must take twice as much of the hydrogen as of the oxygen, the specific gravity of oxygen exceeding that of hydrogen sixteen times. The latter, in the gaseous state, is the lightest natural body known(7).

Caroline. And is it really possible that water should be a combination of two gases, and that one of these should be inflammable air! Hydrogen must be a most extraordinary gas to produce both fire and water.

Mrs B. You should rather say that water is a combination of the *bases* of two gases; for when they combine they lose their gaseous form(8).

Emily. But I thought you said that combustion could take place in no gas but oxygen.

Mrs B. Do you recollect in what the ordinary process of combustion consists?

Emily. In the combination of a body with oxygen, accompanied by the disengagement of light and heat.

Mrs B. When, therefore, I say that hydrogen is combustible, I mean that it readily combines with oxygen. But, like all other combustible substances, it cannot burn unless supplied with oxygen, and also heated to a proper temperature(9).

Caroline. The simply mixing two parts by bulk of hydrogen, with one part of oxygen gas, will not, therefore, produce water.

Mrs B. No; water being a much more dense fluid than the gases, it is necessary, in order to reduce these gases to a liquid, that they should part with the caloric which maintains them in an elastic form(10). But we had better proceed at once to the decomposition of water, and the obtaining of hydrogen gas from it, in order to exhibit its properties. Hydrogen is contained in many other substances besides water; but whenever we wish to obtain it in a pure state, this is always effected by the decomposition of that fluid(11).

Caroline. I should like extremely to see water decomposed. Is there more than one method of doing this?

Mrs B. Yes, several. There are a number of combustible bodies, which at the temperature of ignition have a stronger affinity for the oxygen of the water than hydrogen has, and, consequently, if water in the state of vapour be brought into contact with them, they will deprive it of its oxygen, and the hydrogen will be liberated in the gaseous form(12). Either charcoal

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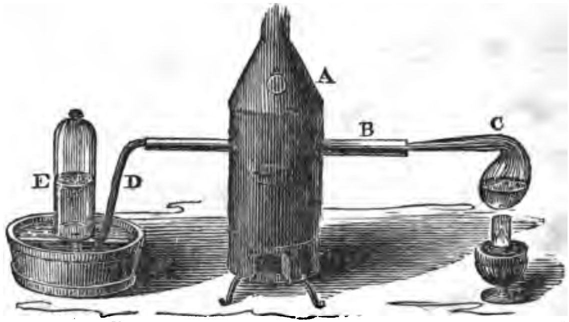
3. Why was hydrogen gas called inflammable air?
4. Is it produced naturally, and in what situations?
5. From what is its name, hydrogen, derived?
6. How is water formed, and what are its constituents?
7. In what proportion, by volume, do the gases combine?
8. Is it proper to say that the gases form water?
9. What is meant when we say that hydrogen is combustible?
10. With what must the gases part, when changed to liquids?
11. From what is hydrogen gas always obtained?
12. Upon what principle may water be decomposed?

or iron, when ignited, will decompose water, and when the latter is employed the hydrogen may be obtained in great purity(13).

Emily. As the hydrogen is combustible, I am puzzled to tell how you can keep it from burning, when in contact with red hot iron.

Mrs B. There are methods of decomposing water which are much more easy than that by heated iron, which is indeed a very troublesome one; but as it is one of the most direct and satisfactory, I will exhibit to you the apparatus by which it is effected, and explain its operation, but without attempting any actual experiment. This will save much time, and answer every useful purpose.

Furnace and gun barrel for decomposing water



[A, the furnace. B, the gun barrel, filled with iron wire in the heated part. C, retort, with water kept boiling. D, the tube which conducts the hydrogen into the receiver E, placed over water.]

This is a small furnace in which most of the metals may be melted, and other processes performed which require considerable heat. Through two openings in its sides any tube which it is desired to heat may be passed. Some iron wire or other shreds of iron are rammed into the middle of a clean gun barrel, so as to occupy a length of six or eight inches. A small retort, half filled with water is luted into the opening at one end. Strips of paper pasted round the joining answer this purpose perfectly well. From the other end a bent tube passes into a receiver for collecting the gas. When the fire is lighted and the gun barrel so placed that the part containing the shreds of iron is exposed to the fire, it soon becomes red hot, and the water in the retort, being in the mean time made to boil, the steam is compelled to pass over the ignited iron, which will decompose it(14).

Caroline. Now I think that I can tell how this decomposition is effected; the strong attraction of the ignited iron for oxygen, enables it to take it from the hydrogen, which escapes in the gaseous form. But, like Emily, I am at a loss to know why so inflammable a substance, so highly heated, does not burn(15).

Mrs B. Yet if I ask you what is necessary to its combustion, you will answer, an elevation of temperature, and the presence of oxygen; now tell me, how it is to obtain the latter?

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13. What two articles are named which will decompose water?
14. Describe the apparatus used for its decomposition.
15. How does the iron operate in promoting it?

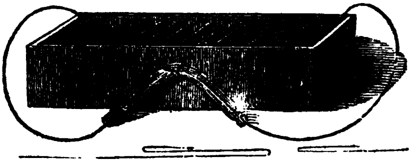
Caroline. Why did we not think of that Emily? The oxygen of the water is taken away from it by the iron, and though highly heated, it is not exposed to the atmosphere, or to any other source of oxygen, and therefore cannot burn(16).

Emily. Water then must be an *oxide of hydrogen*, yet you do not call it so; and the iron, in the process you have described, must also be converted into an oxide of iron(17).

Mrs B. Very well said. Strictly speaking, water is an oxide, but I am sure you will not complain of its familiar name being retained. The iron is, as you correctly observed, converted into an oxide, and is exactly similar to that produced by the burning of iron wire in oxygen gas. It will, of course, be found to have acquired weight from the same cause. Were we to weigh the hydrogen obtained, we should find that for every grain of it, the iron had acquired an addition of eight grains(18).

Caroline. This is altogether as direct and satisfactory a proof of the composition of water as could be desired. But I see that you have the voltaic battery upon the table; I have been anxious to see its power exhibited in decomposing bodies.

Apparatus for the decomposition of water by the voltaic battery.



Mrs B. And you will now witness it in its action upon water, as that fluid can be very readily decomposed by it. For this purpose I fill this crooked glass tube with water, and cork it up at both ends. Through one of the corks I introduce a wire which is connected with the positive pole of the battery, whilst the wire that is connected with the negative pole is made to pass through the other cork. The two wires approach each other sufficiently near for the electrical current to take place.

Caroline. It does not appear to me that you cause the wires to approach so near as you formerly did when you used the battery.

Mrs B. Water being a better conductor of electricity than air, the two wires will act on each other at a greater distance in the former fluid than in the latter.

Emily. Now the electrical effect appears: I see small bubbles of air emitted from each wire.

Mrs B. Each wire acts in decomposing the water; the positive by attracting its oxygen, which is negative; the negative by attracting its hydrogen, which is positive(19).

Caroline. That is wonderfully curious! but what are the small bubbles of air?

Mrs B. Those that proceed from tne positive wire, are the result of the attraction of the oxygen of the water, which is *electro-negative*. This combining with caloric is by that wire set at liberty, and appears in the form of small bubbles of gas or air. In like manner the hydrogen, which is *electro-*

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16. Why does not the hydrogen burn when so highly heated?
17. What does Emily remark respecting the water and the iron?
18. To what will the increased weight of the iron be equal?
19. Describe the decomposition of water by the voltaic battery.

positive, is attracted towards the negative pole, and produces the more numerous bubbles which you see are disengaged in contact with that wire(20).

You must not, however, neglect to observe, that the wires used in this experiment are made of platina, a metal which is not capable of becoming oxidized; for otherwise the wire would combine with the oxygen, and the hydrogen alone would be disengaged(21).

Caroline. But could not water be decomposed without the electric circle being completed? If, for instance, you immersed only the positive wire in the water, would it not combine with the oxygen, and the hydrogen gas be given out?

Mrs B. By no means; the battery cannot act unless the electric circle be completed, so that the fluid can find a passage from one pole to the other(22).

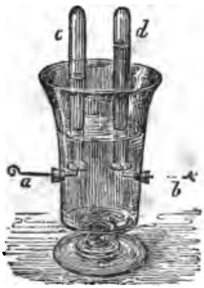
Caroline. I understand it now. But look, Mrs B., the decomposition of the water, which has been going on for some time, does not sensibly diminish its quantity; what is the reason of that?

Mrs B. Because the quantity decomposed is so extremely small. If you compare the density of water with that of the gases into which it is resolved, you must be aware that a single drop of water is sufficient to produce thousands of such small bubbles as those you now perceive.

Caroline. But in this experiment, we obtain the oxygen and hydrogen gases mixed together. Is there any means of procuring the two gases separately?

Mrs B. They can be collected separately with great ease by modifying the experiment with that view. Instead of one tube, two may be employed, as in this apparatus. Two platina wires pass through openings on opposite sides of this glass vessel, which, you see, contains water. Over the inner ends of these wires are two tubes, filled with water, their lower ends being open, and their upper ends closed. On connecting the two wires with the opposite poles of a battery, the oxygen of the water will be disengaged at one wire, and the hydrogen at the other. This wire [*b*] is positive, and will attract the oxygen, which will ascend into the tube [*d*] above it; and as the other wire [*a*] is negative, the hydrogen will ascend into this tube [*c*], and its volume will be exactly double that of the oxygen; these being the precise proportions which form water(23).

Decomposing water by Voltaic Electricity, and collecting the gases separately.



[*a*, The wire connected with the negative; *b*, that connected with the positive pole of the battery; both wires pass through perforations in a goblet containing water. *c*, The tube which receives the hydrogen; *d*, that for the oxygen.

Emily. Then if we were to burn the hydrogen, by means of the oxygen, they would again reproduce the exact quantity of water that has been decomposed(24). We however shall be a long time in collecting enough for that purpose. I am sorry that the decomposition by metals is so inconvenient, as it would be very satisfactory to experiment with the hydrogen upon a larger scale.

Mrs B. Hydrogen is as readily obtained in large quantities as any of the gases, but by a process, the explanation of which is more complex than

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20. In what way was the principle of its operation explained?
21. Why are platina wires used in the experiment?
22. For what reason must the electric circle be completed?
23. Describe the apparatus for obtaining the gases separately?
24. Were these gases reunited, what would be the consequence?

produced will exceed the bulk of water decomposed, about seventy-five thousand times(33). It is on account of its levity that it is employed for filling air balloons, which float in the atmosphere in consequence of their displacing a weight of common air greater than that of the hydrogen, the balloon, and its appendages. It is for this same reason that a substance lighter than water floats on that fluid(34).

Caroline. Can we not fill a bladder with this gas, and cause it to ascend?

Mrs B. No; a bladder cannot be made sufficiently thin and light for this purpose; but you will presently see how rapidly soap bubbles filled with hydrogen will rise in the atmosphere. I will first however show you its inflammability, which is one of its most important properties; as it is concerned in most of the combustions which are accompanied by flame.

Into this bottle [Fig. 1.] I put the materials for making hydrogen, and insert a tube, fitted by means of a cork, into the neck of it. Through this tube the gas will issue in a continued stream, and when lighted will, as you see, continue to burn. This is sometimes called the philosophical candle(35).

Philosophical Candle.

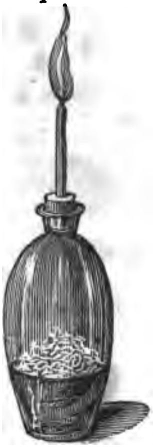

Fig. 1.

Two glass vessels for showing the levity of hydrogen gas.

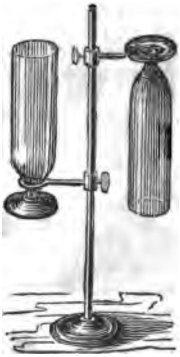

Fig. 2.

Emily. How prettily it burns with a beautiful pale blue flame. I suppose that the product of its combustion is nothing but water.

Mrs B. You are right; and were we to collect it we should find that every grain of hydrogen had combined with eight grains of the oxygen of the atmosphere, and produced nine grains of water(36).

Before showing you another experiment on its inflammability, I will exhibit to you one which will manifest its levity. I fill these two glasses with hydrogen, and place them with the open mouth of one up, and of the other down. [Fig. 2.] We may allow them to remain for several minutes in this situation, when on applying a taper to that with the mouth up, it will be

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33. Why is the volume of hydrogen produced so great?
34. Why are air balloons filled with hydrogen gas?
35. What is it that is called the philosophical candle?
36 What is said respecting the product of its combustion?

found to contain atmospheric air only; whilst the gas will still remain in the other, and will take fire, and burn(37).

Caroline. In this case the hydrogen being lighter than the common air, ascended from the first glass, and the atmosphere occupies its place; whilst the very levity of the hydrogen tended to keep it in the inverted glass, as it could not ascend through it(38).

Mrs B. Upon this principle a receiver may be filled with hydrogen, without the use of a pneumatic cistern; by taking a bottle and tube similar to that which we used for the philosophical candle, and allowing the gas to escape through the tube, and pass into a receiver held over it. [Fig. 1.] It will by its levity rise to the top of the receiver, and as it accumulates will force the atmospheric air out, and occupy its place(39).

This same principle may be applied to gases which are heavier than atmospheric air; but in this case the tube must be bent so as to pass down to the bottom of a bottle, standing with its mouth upwards: this you will witness at a proper time. Gases which are absorbed by water may also be sometimes thus collected, all of them being either heavier or lighter than atmospheric air.

Emily. We feel much obliged, Mrs B., by this kind of information, as it will enable us sometimes to try an experiment which we otherwise could not attempt from want of the usual means.

Filling receiver with hydrogen gas without using a pneumatic cistern.

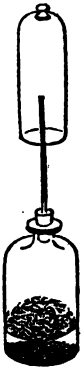

Fig. 1.

Candle extinguished and relighted by hydrogen.

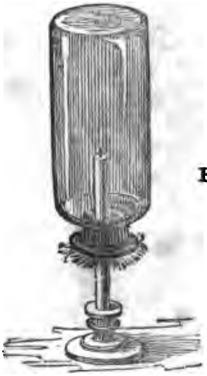

Fig 2.

Mrs B. I pass this inverted phial of hydrogen over this lighted candle. [Fig. 2.] The gas takes fire as soon as it touches the flame, and continues to burn at the mouth of the vessel; but the candle is extinguished the moment it is completely immersed in the hydrogen, and is relighted in passing through the flame when I withdraw it; and this, as you see, can be repeated a number of times(40).

Caroline. I am delighted with this experiment, it exemplifies so clearly the difference between a combustible and a supporter of combustion. What you have told us about oxygen explains the whole. Without this

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37. How may its levity be shown by two glasses?
38. In what way is this phenomenon explained?
39. How may hydrogen gas be collected without a pneumatic cistern?
40. What experiment is performed with hydrogen and a candle?

same oxygen, neither the hydrogen nor the candle can burn. There is no oxygen in the phial, and therefore the candle is extinguished; but at its mouth the oxygen of the atmosphere keeps up the combustion, and your philosophical candle relights your common one(41).

Mrs B. Your happy application of what you have already learned, is to me a most gratifying recompense for the little time which I have devoted to your instruction. I have nothing to add to the explanation which you have given, but will proceed to show you some other examples of the combustion of hydrogen. Did you not observe that when we set fire to the hydrogen, at the mouth of the jar, that it kindled with a slight explosion?

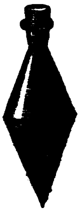
Emily. Yes, and I was just about to ask you the cause of this, as it afterwards burnt so quietly and silently.

Mrs B. Just at the mouth of the jar, the oxygen of the atmosphere, and a portion of the hydrogen had intermingled. The whole of this portion therefore took fire instantaneously, every particle of hydrogen being in contact with a particle of oxygen(42). Can you not perceive what would be the consequence were we to ignite the two gases in a state of complete mixture.

Emily. I think I do: as a slight explosion was produced by a small portion, I should apprehend that a larger quantity would explode with corresponding power(43).

Mrs B. And such is the fact. Observe that I fill this tin vessel with a mixture of one part of hydrogen with two of atmospheric air, and put a cork in the mouth of it. At its opposite end is a small hole like a touch hole, to which I will apply a lighted taper, when the gases will explode and blow the cork out with considerable force(44).

Tin vessel for exploding gases.



Caroline. Oh! Well, I had no idea of such a report; why it was like the firing of a gun! Is it possible that it was produced by the two gases only?

Mrs B. The report was certainly loud, but not exactly like that of a gun. Had we taken pure oxygen, with a proper portion of hydrogen, it would have been much louder. Had I used oxygen, however, I should have mixed with it twice its bulk of hydrogen; but employing atmospheric air I added but one half its bulk of hydrogen. Can you tell the reason of this(45)?

Emily. I think [illegible]n explain it: there is so much nitrogen in atmospheric air, that ha[illegible] bulk of hydrogen is sufficient for the oxygen, as the latter combines with twice its volume of the former(46). I do not however understand the cause of the explosion; for as the two gases unite, and become water, I should suppose that instead of expansion, there would be a sudden condensation.

Mrs B. You are perfectly correct in your explanation, and your difficulty will be easily solved. The two gases, the bases of which unite to form water, give out a large portion of their combined heat, which becoming free, rarefies the vapour at the moment of its production, and thus gives rise to the explosion, like gunpowder and other similar compounds(47). The intense heat given out in this combustion, has, as you will hereafter learn, been employed by the chemist in fusing and volatilizing some of the most refractory articles.

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41. How is this phenomenon explained?
42. From what cause does this gas kindle with a slight explosion?
43. What would result from a complete mixture?
44. In what way may the gases be exploded?
45. What volumes of oxygen and of common air are used?
46. For what reason is this difference made?
47. In what way is the loud explosion accounted for?

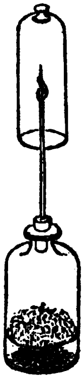
Caroline. Why is it necessary to kindle the hydrogen in order to its combination with oxygen? would they not unite, slowly at least, by merely mixing them together?

Mrs B. Perhaps I cannot satisfactorily answer your question, why we must apply heat; but you have already learned that it is one of the most powerful agents in producing chemical changes. The bases of the two gases may be made to combine by sudden condensation, which causes the particles to approximate, and forces out a portion of the heat of capacity; but this is no easy or safe experiment(48).

Emily. By what means can we collect the water which is produced by the combination? In the explosions and combustions which we have seen, it is dissipated as it is formed.

Formation of water by burning hydrogen within a bell glass.

Mrs B. We can very readily show the actual formation of water, by merely holding a piece of cold metal over the flame of burning hydrogen: the watery vapour will be condensed upon it, so as to be quite apparent, and indeed to run off in drops. By holding a cold glass receiver over the flame, the vapour of water will be condensed on the inside of it, and this will continue until the receiver itself becomes heated(49).



Caroline. Yes, indeed; the glass is now quite dim with moisture! How glad I am that we can *see* the water produced by this combustion.

Emily. It is exactly what I was anxious to see; for I confess I was a little incredulous.

Mrs B. If I had not held the bell glass over the flame, the water would have escaped in the state of vapour, as it did in the former experiments. We have here, of course, obtained but a very small quantity of water; but the difficulty of procuring a proper apparatus, with sufficient quantities of gases, and the length of time required for the experiment, prevent my showing it to you on a larger scale.

The composition of water was suspected by the celebrated Mr Watt, and was discovered at about the same time, both by Mr Cavendish, in England, and by the celebrated French chemist, Lavoisier(50). The latter invented a very perfect and ingenious apparatus, to effect with great accuracy, and upon a large scale, the formation of water by the combination of oxygen and hydrogen gases. Two tubes, conveying due proportions, the one of oxygen, the other of hydrogen gas, were inserted at opposite sides of a large globe of glass previously exhausted of air. The stream of hydrogen gas was kindled within the globe, by the electrical spark, at the point where the two came in contact. They burnt together, that is to say, the hydrogen combined with the oxygen, the caloric was set at liberty, and a quantity of water was produced, exactly equal in weight to that of the two gases introduced into the globe.

Caroline. And what was the greatest quantity of water ever formed in this apparatus?

Mrs B. Several ounces; indeed, very nearly a pound, if I recollect right; but the operation lasted many days(51).

Emily. This experiment must have convinced all the world of the truth of the discovery. Pray, if improper proportions of the gases were mixed and set on fire, what would be the result?

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48. Can the gases be made to explode without ignition?
49. How can the formation of water be exhibited?
50. By whom was the composition of water discovered?
51. What celebrated experiment is mentioned?

Mrs B. Water would still be formed, but there would be a residue of either one or other of the gases; because, under these circumstances, hydrogen and oxygen will combine only in the proportions requisite for the formation of water.

One of the methods employed to ascertain the proportionate quantity of oxygen in the atmosphere, is the combustion of hydrogen in a confined portion of it, by which the whole of the oxygen may be separated, the nitrogen alone remaining, or more commonly nitrogen mixed with a portion of hydrogen(52). There are several other methods of separating the oxygen from the nitrogen of the atmosphere. To this I shall call your attention more particularly when examining the properties of phosphorus.

Emily. Pray is there not some danger of an explosion from the accidental mixture of atmospheric air with hydrogen, when we suppose that we are only going to burn the latter?

Musical sounds caused by the combustion of hydrogen in tubes.

Mrs B. Great caution is necessary to prevent it. I have again prepared the bottle and tube, to obtain the flame of hydrogen gas, and you may observe that I allow it to escape for some time before setting fire to it. I do this in order to be sure that all the atmospheric air is expelled from the bottle, otherwise it might be blown to pieces, and much mischief done by the scattering of its contents(53).

I am about to show you another curious effect produced by the combustion of hydrogen gas, which I now kindle with the taper. I have here a glass tube open at both ends, which I place over the burning jet.

Emily. What a strange noise it produces, something like the Æolian harp, but not so sweet.

Caroline. It is very singular indeed; but I think rather too powerful to be pleasing. Pray how is this sound accounted for(54)?

Mrs B. These musical tones are considered as a continued series of explosions within the tube(55). Tubes of various materials and dimensions produce different tones, some very sweet, and others quite harsh, and with a commotion which not unfrequently extinguishes the flame. Tubes of different materials, flasks, phials, and hollow globes, may be used in the experiment; and other combustible gases and vapours answer instead of hydrogen(56).

Caroline. By the preparation which you have made I think that we are now to see some of the fragile air balloons which you promised us.

Mrs B. We shall now fill some soap bubbles with hydrogen gas instead of atmospheric air, and you will see with what ease and speed they will ascend, from the lightness of the gas.—Will you mix some soap and water, whilst I fill this bladder with the gas contained in the receiver which stands on the shelf in the water bath(57)?

Caroline. What is the use of the brass stop-cocks which are attached to the top of the receiver?

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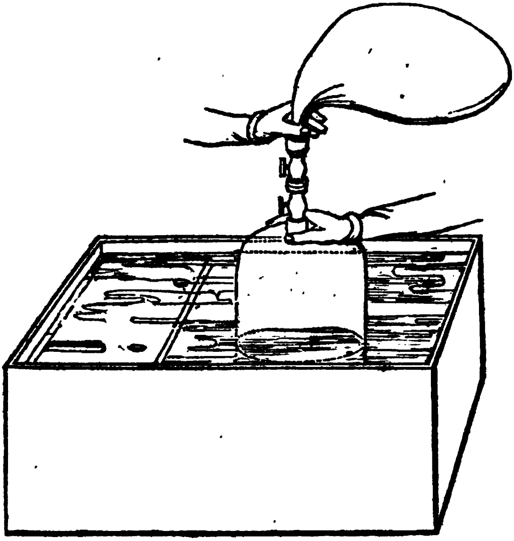
52. To what use is the combustion of hydrogen applied?
53. What precaution is necessary when experimenting with hydrogen?
54. How may musical tones be produced by burning it?
55. In what way is the noise accounted for?
56. Is the effect confined to hydrogen and to tubes of glass?
57. What experiment is mentioned with soap bubbles?

Apparatus for transferring Gases from a Receiver into a Bladder, for blowing Bubbles, or for other Purposes.



Mrs B. It is to afford a passage to the gas, when required. There is, you see, a similar stop-cock fastened to this bladder, which is made to fit on the receiver. I screw them one on the other, and now turn the two cocks, to open a communication between the receiver and the bladder; then, by sliding the receiver off the shelf, and gently sinking it into the cistern, the water rises in the receiver, and forces the gas into the bladder(58).

Caroline. Yes. I see the bladder swell as the water rises in the receiver.

Mrs B. I think that we have already a sufficient quantity in the bladder for our purpose. We must be careful to turn the upper key before we separate the bladder from the receiver, or the gas would escape. Now I must fix a pipe to the stopper of the bladder, and by dipping its mouth into the soap and water, take up a few drops. I now again turn the cock, and squeeze the bladder, in order to force the gas into the soap and water, at the mouth of the pipe.

Emily. There is a bubble, but it bursts before it leaves the mouth of the pipe.

Mrs B. We must have patience and try again. It is not so easy to blow bubbles by means of a bladder, as simply with the breath.

Caroline. Now a bubble ascends. Owing to its levity, it rises with great rapidity, and thus shows very satisfactorily the nature of those larger and stronger machines which enable men to rise above the clouds(59).

Mrs B. We will now blow some with a mixture of oxygen and hydrogen in due proportions. These will not ascend with quite so much rapidity as the others; but if you catch them in their ascent with a lighted taper, they will

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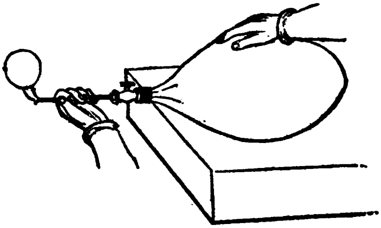
58. Describe the mode of filling a bladder with hydrogen or other gas.
59. How are such bubbles blown, and what do they exemplify?

give a report like a pistol(60). I have now filled the bladder with the mixed gases, and you must be careful not to touch the bubble before it has escaped from the pipe, or the whole contents of the bladder will explode. Try it Caroline, but mind the caution I have given.

Soap Bubbles blown by means of a Bladder



Caroline. How awkward I must be; three have escaped and I have not been able to touch one of them! If I do not succeed better in the next trial I will hand the taper to Emily. I am lucky at last, and will not risk my credit by another attempt. How powerfully explosive this compound must be to produce so loud a report in so small a quantity and with so thin an envelope!

Mrs B. Were we to dip the bowl of the pipe into the vessel of soapsuds, and continue to blow until the bubbles had piled themselves up on the surface, and then touch them with a lighted taper, the explosion would be absolutely deafening(61).

Emily. I had no conception that the subject of water and its constituents was so extensive and so full of interest. With respect to its composition, we have the most perfect proof, both analytical and synthetical; and it seems in its decompositions and recompositions to perform a very important part indeed in the economy of nature.

Mrs B. You have yet but a very inadequate idea of its uses and combinations. There are but few compounds into which water, or one or both of its constituents does not enter, and but few agents more universally diffused. It exists in a solid state in most rocks and stones, in many instances so intimately combined with them as not to be separated at a red heat. Substances with which it is thus intimately combined are called *Hydrates*(62). Water is capable of absorbing all the gases, some of them in very minute, and others in very large proportions(63). Water is a solvent of more substances than any other fluid. Hence we rarely or never find it pure in nature; as it dissolves a portion of many of the minerals over which it passes in the bowels of the earth(64). The catalogue of its uses would be almost endless.

Caroline. Do oxygen and hydrogen combine in any other proportions than those which form water? I do not recollect that you have intimated to us that there is any such compound.

Mrs B. Until within a very few years, no other combination of oxygen and hydrogen was known; but in 1818 Thenard, one of the most celebrated chemists of France, published an account of a new compound which he had

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60. What variation of the experiment is stated?
61. In what manner may a louder explosion be produced?
62. What is said of the numerous combinations of water?
63. What, of its absorbent power?
64. What is remarked respecting it as a solvent?

artificially formed, of oxygen and hydrogen, containing twice the relative quantity of oxygen which exists in water. This he called **DEUTOXIDE OF HYDROGEN**, because it contains two atoms, or proportionals, of oxygen to one of hydrogen(65).

It is a corrosive fluid, much heavier than water, and possessing several very peculiar properties; but neither these nor the mode of its preparation are important for you to know. When heated to about 60° it gives out pure oxygen, and is converted into water(66).

CONVERSATION XIII.

ON SULPHUR AND ITS COMBINATIONS WITH OXYGEN AND HYDROGEN.

Properties of the Non-metallic Simple Inflammables. Natural History of Sulphur. Sublimation. Combustion of Sulphur in Atmospheric Air. Acid formed by its Combustion. Absorption of Gases by Water. Their Liquefaction. Bleaching. Manufacture of Sulphuric Acid. Sulphuretted Hydrogen. Harrowgate Waters. Hydrosulphurets.

Mrs B. The subject of our last conversation has made you acquainted with one of a class of bodies sometimes called the SIMPLE INFLAMMABLES; that is, substances which have never been decompounded,—which are capable of combining with oxygen, and of emitting light and heat when the combination is rapid,—and which form with it acids or oxides(1).

Having attended to the first member of this class, hydrogen, we shall take up three of the others in the following order: Sulphur, Phosphorus, and Carbon(2); deferring the remainder, because I think they may be more advantageously introduced out of what might seem to be their regular turn.

Caroline. But I understood that the metals were all inflammable, and that they were also simple bodies; and, beside these, there are many other combustibles which are not contained in your list.

Mrs B. The metals are certainly simple inflammables, but on account of their distinctive characteristics, they are usually placed in a class by themselves; those just enumerated, with a few others, being frequently denominated the *non-metallic simple inflammables*(3). With respect to the *many other* combustibles to which you allude, they are compounds, and are therefore expressly excluded from the class in question.

Caroline. I am glad that we have again a solid body to examine, one that we can see and touch; although I must acknowledge that in investigating its properties I do not anticipate the gratification of all the senses. The smell of brimstone is to me one among the most offensive; I dislike even to light a match.

Mrs B. Pure sulphur has but little or no odour, and you have fallen into the common error of confounding the smell of one of the products of its combustion, with that of the simple article. The smell of a burning match is not the smell of sulphur. Sulphur is seldom discovered in nature in a pure

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65. What other combination is there of oxygen and hydrogen?
66. What particulars are stated respecting it?
1. What properties distinguish the *simple inflammables?*
2. What four bodies, belonging to that class, are named?
3. How are they distinguished from the metals, which are also simple inflammables?

unmixed state(4). So great is its affinity for other substances, that it is almost constantly found combined with some of them. It is most commonly united with the metals, under various forms, and from some of these combinations is separated by a very simple process. It exists likewise in many mineral waters; and some vegetables, especially those of the *cruciform tribe*, yield it in various proportions. It is also found in animal matter; in short, it may be discovered in greater or less quantity in the mineral, vegetable, and animal kingdoms(5).

Emily. I have understood that large quantities of sulphur are found in the island of Sicily, and in other volcanic countries.

Mrs B. The larger portion is, I believe, supplied from Sicily, the Lipari islands, and some other parts of Italy, where it is found in abundance, and sometimes in a state of very great purity; the continued interior heat of the earth in these places causing it to rise to the surface by *sublimation*(6).

Emily. Pray, what is sublimation?

Mrs B. It is a process very analogous to that of distillation. The difference between them is, that in sublimation we operate upon solids, and in distillation upon fluids. There are several solid substances which may be converted into vapour by heat, and which condense again by cold. Sulphur is one of these, and advantage is taken of this property to separate it from the fixed earthy or metallic substances with which it is commonly combined(7).

Caroline. Pray, Mrs B., what is the difference between the fine powder which is called *flowers of sulphur*, and common roll brimstone.

Mrs B. The article in this phial, labelled *flowers of sulphur*, is sulphur which has been sublimed, or volatilized by heat(8). This process can be shown, in the small way, by putting some pieces of sulphur into a glass flask, (fig. 1.) inverting a second flask over it, and applying heat to the lower vessel. The sulphur will then fuse, and when it acquires a temperature of about six hundred degrees, it will rise in vapour, and be condensed about the neck and body of the upper vessel(9). In the large way the sulphur is melted in iron pots, and ascends in vapour into a chamber above, upon the walls of which it is condensed in the form of flowers(10). You now perfectly understand, I suppose, what is meant by sublimation?

Emily. I believe I do. Sublimation appears to consist in destroying, by means of heat, the attraction of aggregation of the particles of a solid body, which are thus volatilized; and as soon as they lose the caloric which produced that effect, they are deposited in the form of a fine powder(11).

Mrs B. In the case of sulphur a fine powder is produced, but the greater number of solids which undergo sublimation, form in their condensation a concrete mass(12).

Sulphur, chemically speaking, is exactly the same substance, whether in the form of lumps or in powder. For if this powder be melted, it will, in cooling, be restored to the same solid state in which it was before its sublimation?

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4. Is sulphur often found in a state of purity?
5. With what different articles is it said to be combined?
6. Whence is a large portion of it obtained?
7. What is intended by *sublimation?*
8. What is the difference between flowers of sulphur and roll brimstone?
9. How may its sublimation be exhibited?
10. How is it performed in the large way?
11. In what does the process appear to consist?
12. Are sublimed articles generally in the form of powder?

Caroline. But if there is no real change produced by the sublimation of the sulphur, what is the use of that operation?

Mrs B. It divides the sulphur into very minute parts, in which state it is largely used in medicine. It is also a means of purification, as it separates it completely from all earthy and other fixed substances(13).

Caroline. Sublimation appears to me like the beginning of combustion, for the completion of which one circumstance only is wanting, the absorption of oxygen.

Sublimation of Sulphur.

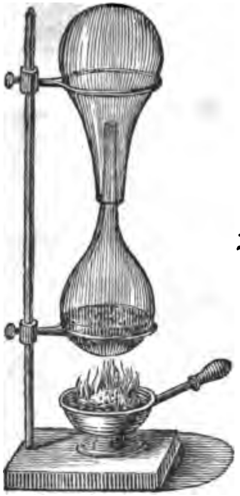

Fig. 1.

Sulphur burnt in Atmospheric Air

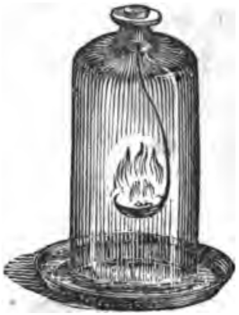

Fig. 2.

Mrs B. But that circumstance is every thing. No essential alteration is produced in sulphur by sublimation; whilst in combustion it combines with oxygen, forms a new compound, totally different, in every respect, from sulphur in its pure state(14). We shall now *burn* some sulphur in atmospheric air, in the same way in which we lately burnt it in oxygen gas. I have in the present instance (fig. 2.) put some flowers of sulphur into the copper spoon, and this I ignite by means of a red hot wire. As I place it in the receiver, over water, the vessel becomes filled with the same kind of dense vapour which you witnessed in the former experiment; and you will soon perceive the water rise in the receiver, a little above its level in the plate(15).

Emily. The information which you gave us when on the subject of oxygen, will, I think, suggest an explanation of this. The sulphur is now combining with the oxygen of the air, and forming sulphuric acid; which mixing with the water, causes a partial vacuum in the glass, and, of course, the pressure of the atmosphere forces the water to rise in the receiver(16).

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13. What advantages are obtained by subliming sulphur?
14. What is the essential difference between sublimation and combustion?
15. Describe the experiment of burning it in atmospheric air.
16. Why does the water rise in the receiver?

Mrs B. You have made a very good attempt at an explanation, although it is not quite correct. It is *sulphurous*, and not sulphuric acid which is formed(17). SULPHUROUS ACID, at the common temperature and pressure of the atmosphere, is a colourless, invisible gas. When water is present it absorbs this gas and converts it into the liquid form. One pint of water will absorb thirty-three pints of this gas. It is readily distinguished from all others by its strong suffocating odour. What Caroline called the smell of brimstone, is the smell of this acid. When you set fire to the sulphur on the end of a match, sulphurous acid is formed, and mixing with the atmosphere produces that offensive smell with which every one is familiar(18).

Caroline. We have here, then, two curious examples of the effect of chemical combination. The solid yellow sulphur is converted into an invisible gas; and two bodies, sulphur and oxygen, which in their separate state have no smell, acquire a most pungent odour.

Emily. Yes, and a gas by merely coming in contact with water, is absorbed by it in a quantity equal to thirty-three times the bulk of the water, and is thus made to assume the liquid form(19).

Mrs B. I am much pleased with your reflections, as they show both attention and judgment. Large as is the quantity of sulphurous acid which combines with water, you will learn that there are some other gases of which it absorbs several hundred times its own bulk. Gases which have been thus absorbed, are expelled again unaltered, by heating the water(20). Sulphurous acid may be converted into the liquid state either by pressure, or by intense cold, without the presence of water; but it will again assume the gaseous form when the pressure is removed, or the temperature raised. Several of the gases have been thus brought to the liquid state, although less readily than sulphurous acid(21).

Emily. If this gas is invisible, what caused the white vapour which we saw in the glass, and which has now disappeared?

Mrs B. This was caused by the union of the gas with the watery vapour contained in the glass, and which is now completely absorbed by the water. In our experiments you will frequently witness a similar appearance.

Caroline. It bears then some resemblance to the appearance of steam, when it is partially condensed by the atmosphere as it issues from boiling water.

Emily. Is this gas applied to any use? It is so suffocating that I should think it difficult to employ it.

Mrs B. It is used in bleaching, as it discharges many of the lighter colours. Straw and silk, for example, are both whitened by it. The articles to be bleached are moistened and hung up in a box, upon the bottom of which is placed a dish containing sulphur; this is to be ignited, and the box covered up, when the moisture absorbs the gas which acts upon the articles, and destroys their colour. A rough cask, or packing case, answers the purpose, as the air must not be perfectly excluded, or the combustion would cease. The operation should be performed out of doors(22).

Caroline. Well, I declare I will turn bleacher, and begin by an experiment upon my old straw hat. Cannot we now, Mrs B., bleach something by means of the acid which you have formed?

Mrs B. Although the water has acquired a strong smell, its acid powers are very feeble, as but a very small quantity of the gas has been produ-

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17. What acid is formed in the combustion of sulphur?
18. What is said respecting its nature and properties?
19. What does it exemplify respecting chemical combination?
20. Are any other gases absorbed by water?
21. Can any of them be rendered liquid: and how?
22. For what purpose, and in what way is sulphurous acid used?

ced. We however can readily bleach this red rose by holding it over the vapour of burning sulphur. Three or four matches held together will suffice. I will light these, and hold the rose so that the gas, but not the flame, shall come in contact with its petals(23).

Emily. How rapidly the effect is produced, and how beautifully variegated the rose appears! Where the gas has touched it, it is quite white, whilst the other parts have retained their original colour.

Caroline. Whatever beauty it may have acquired, is certainly not accompanied by any improvement in its smell.

Mrs B. Articles bleached by sulphurous acid, soon lose their unpleasant odour by exposure to the atmosphere. Growing flowers may be thus bleached without destroying them, and white and red roses be thus exhibited upon the same bush(24).

Emily. I suppose, Mrs B., that sulphur burned in oxygen is converted into SULPHURIC ACID; whilst in atmospheric air it only obtains oxygen enough to form the sulphurous?

Mrs B. If we burn sulphur in dry oxygen, we obtain sulphurous acid only: when the experiment is performed over water, a small portion of sulphuric acid is produced(25). Were we, however, to depend upon this process for the production of sulphuric acid, it would, instead of one of the cheapest, be the dearest of the whole class.

Caroline. This acid appears to be an agent of so much importance, that I should like to know how it is obtained?

Mrs B. I can give you only a general idea of the processes followed, but perhaps this will be enough to satisfy you. Sulphuric acid, was, until of late years, all obtained from common copperas, by a process which is still pursued in Germany(26). Copperas, you may recollect, is the *sulphate of iron* of the chemists, as it consists of sulphuric acid, united to the oxide of iron. This salt is dried, then put into a proper retort, in which it is heated red hot. The sulphuric acid is thus expelled, and is collected in a receiver, the oxide of iron remaining alone in the retort(27). The liquid thus obtained appears of an oily consistence, and as the salt was often called *green vitriol,* the fluid was denominated *oil of vitriol*(28).

The largest portion of this acid is now made by the direct combustion of sulphur. The process is performed in a chamber lined with lead, and having water on the floor. The sulphur intended to be burnt is mixed with nitre, which, when heated, supplies a large portion of oxygen, whilst the atmospheric air also aids in the oxygenation. After the lapse of many days the water becomes extremely acid; it is then put into proper vessels and boiled. The water being more volatile than the acid, is evaporated, leaving the latter in a state of concentration, and possessing a specific gravity nearly double that of water(29).

Emily. From what you have told us I should have supposed that sulphurous acid would still have been the principal product of this combustion.

Mrs B. And so it is; but sulphurous acid, exposed to the action of air and moisture, gradually absorbs oxygen from the former, and is thus changed into sulphuric acid. This change takes place in the leaden chamber.

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23. How may a rose be bleached by sulphurous acid gas?
24. What is said further on this point?
25. What acid is formed when sulphur is burned in oxygen?
26. From what was sulphuric acid formerly procured?
27. What is copperas, and how was the acid obtained from it?
28. Why was sulphuric acid called oil of vitriol?
29. How is this acid manufactured by combustion?

Some of the attending circumstances are, however, too intricate for you to understand at present(30).

Emily. The sulphuric acid in this bottle has no smell whatever.

Mrs B. The effect of chemical combination is here again exemplified. The materials composing the sulphurous and sulphuric acids are the same; but in the latter the quantity of oxygen is increased one half. By this two remarkable changes are produced; the stronger acid is without odour, and instead of existing in the gaseous state, this liquid acid requires a temperature of six hundred degrees to convert it into vapour(31).

There are two other compounds of sulphur and oxygen known to the chemist, each possessing acid properties. They are artificially formed by complicated processes, and the mere fact of their existence is enough for you to know(32).

Caroline. The Harrowgate waters, or sulphur springs, as they are sometimes called, I suppose contain sulphur in solution.

Mrs B. Sulphur is insoluble in water alone, but you have seen that its combinations with oxygen are soluble. Sulphur combines with hydrogen, and forms a gas called SULPHURETTED HYDROGEN(33). This gas, like sulphurous acid, is absorbed by water, although in much smaller quantity. The Harrowgate waters contain *sulphuretted hydrogen*, and derive their medicinal properties from its presence(34).

Emily. Allow me to ask what is meant by a *sulphuret?* We have had sulphites and sulphates, but I suppose that this new name indicates some new combination.

Mrs B. Do you recollect how the sulphites and sulphates are formed?

Emily. I think I do. In the former, sulphurous acid has combined with a base, and formed a salt; and in the latter, sulphuric acid has entered into a similar combination(35).

Mrs B. Very well: both these names, therefore, show the presence of an acid; but sulphur itself combines with many bodies without first uniting to oxygen, and the products are in this case called sulphurets. Many of the ores of metals are sulphurets: thus we have sulphuret of iron, which consists of sulphur and iron only, whilst if oxygen enough were present, the sulphur would be acidified, and a sulphate of iron formed(36). Sulphuretted hydrogen, or sulphuret of hydrogen, means a combination of these two bodies only. You will presently learn that there are likewise phosphurets, carburets, &c.; the termination *uret* being appropriated to the combinations of simple non-metallic combustible bodies with each other, and with the metals, alkalies, and earths. Where a compound is a gas, it is usual to add *ted* to the termination *uret*, as *sulphuretted hydrogen* instead of sulphuret of hydrogen(37).

Caroline. I must confess that if the sulphuretted hydrogen resembles the water which contains it, I am not anxious to experiment with it; although it would be right to know how it is produced.

Mrs B. It is certainly a very offensive gas, having the odour of putrefying eggs. It is also very deleterious when breathed, although medicinal

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30. How does sulphurous become sulphuric acid?
31. What are their characteristic differences?
32. Are there any other combinations of sulphur and oxygen?
33. What combination does it form with hydrogen?
34. What mineral waters contain this gas?
35. What is intended by *sulphites* and *sulphates?*
36. What is meant by *sulphurets?*
37. What is said of the termination in *uret* and *uretted?*

when taken into the stomach(38). It may be readily obtained from some of the metallic sulphurets. If, for example, instead of pure iron, we employ a compound of iron and sulphur called sulphuret of iron, and treat it with sulphuric acid and water, just as we did the iron in preparing hydrogen gas, we should obtain sulphuretted hydrogen. The hydrogen of the decomposed water, would, at the moment of its formation, dissolve a portion of the sulphur, and thus become sulphuretted. It may also be prepared by heating sulphur in hydrogen gas; but in this case its formation is less perfect than when obtained by means of the sulphuret of iron(39).

This gas must often be formed spontaneously in the earth, as the springs which contain it are found in almost every country.

Caroline. And could not such waters be made artificially by impregnating common water with this gas?

Mrs B. Yes; they can be so well imitated, as perfectly to resemble the Harrowgate waters(40).

Emily. In what way can the sulphur be separated from the hydrogen in these waters?

Mrs B. It requires no effort to effect this, as it takes place spontaneously. The water which runs from these springs deposites the sulphur; the hydrogen combining with the oxygen of the atmosphere, and forming water, while the sulphur, being insoluble when alone, is precipitated. There are some runs of water in which this deposite has, in the lapse of ages, accumulated to a depth of two or three feet. Even in bottles, when closely corked, a portion of the sulphur will separate and form an incrustation on the glass(41).

Caroline. Sulphuretted hydrogen must of course be inflammable, as both the materials of which it is compounded are so; and the products of its combustion I should suppose would be water and sulphuric acid.

Mrs B. You are nearly correct, but not quite so: when this gas is burned in atmospheric air, water and *sulphurous* acid are formed, the sulphur and hydrogen both, as your remark indicates, uniting with oxygen(42).

Sulphuretted hydrogen has been, by some chemists, ranked among the acids under the name of *hydro-sulphuric acid*(43)

Caroline. That seems strange indeed: where the acidifying principle, oxygen, is not present, it would violate all the notions we have acquired, to admit that an acid can exist.

Mrs B. Have you already forgotten that, although oxygen is the most common source of acidity, it is no longer admitted as *the acidifying principle?* All the acids we have yet spoken of, it is true, are formed by its union with a base; but you have yet to learn that hydrogen also may contribute to the formation of an acid, and in fact that the term *acidifying principle* ought not to be appropriated to any body, or class of bodies; as acidity results from the chemical combination of different substances, one of which is as necessary as the other to the production of the acid, although we usually call one the base, and the other the acidifying principle(44).

Sulphuretted hydrogen has not a sour taste; but it reddens blue vegetable infusions, and combines with the alkalies and some of the earths, neutrali-

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38. What properties does *sulphuretted hydrogen* exhibit?
39. By what processes may it be obtained?
40. Can such waters be artificially made?
41. Is the sulphur readily separated from the hydrogen?
42. What are the products of its combustion?
43. What have some chemists accounted sulphuretted hydrogen?
44. What remarks are made respecting an acidifying principle?

zing their properties, and forming with them crystallizable compounds, analogous to the salts. These compounds are called *hydro-sulphurets*(45).

We shall now dismiss the subject of sulphur; our next lesson will be upon phosphorus.

Caroline. I confess that I shall be quite willing to enter upon a new subject; for although that of sulphur has proved much more interesting than I had anticipated, still it has been less so than the consideration of some of the simple bodies which have preceded it.

CONVERSATION XIV.

ON PHOSPHORUS, AND SOME OF ITS COMBINATIONS.

Discovery of Phosphorus. Substances in which it is contained. Its Combustion. Phosphoric and Phosphorous Acids. Phosphuretted Hydrogen. Nascent State of a Gas. Phosphuret of Lime. Modes of procuring Phosphuretted Hydrogen. Eudiometry and Eudiometers. Application of Phosphorus and of Hydrogen to Eudiometry.

Mrs B. PHOSPHORUS, a portion of which you see covered with water in this phial, is considered by chemists as a simple body, although both it and sulphur have by some been thought to contain hydrogen; but the quantity which has been detected in them is so small, as to render it probable that if really present it was accidentally so.

Phosphorus was first discovered by Brandt, a chemist of Hamburg, whilst employed in researches after the philosopher's stone; but the method of obtaining it remained a secret till it was a second time discovered by Kunckle, in the year 1680(1). Phosphorus is generally moulded into small sticks of a yellowish colour. It has a consistence resembling bees-wax(2), and may be readily cut by a knife.

Caroline. I do not understand in what the discovery consisted: there may be a secret method of making an artificial composition; but how can you talk of *making* a substance which naturally exists?

Mrs B. A body may exist in nature, so closely combined with other substances, as to elude the observation of chemists, or to render it extremely difficult to be obtained in its separate state. This is the case with phosphorus, which is so intimately combined with other bodies, that its existence remained unnoticed, till Brandt discovered the means of obtaining it free from other combinations. It is found in all animal substances, and is now extracted chiefly from bones by a chemical process. Bones consist principally of lime combined with an acid having phosphorus for its base: they are therefore a *phosphate of lime*(3).

Phosphorus exists in minute quantities in certain plants that bear a strong analogy to animal matter in their chemical composition.

Emily. But is it never found in its pure separate state?

Mrs B. Never; and this is the reason why it remained so long undiscovered(4).

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45. What respecting the combinations of sulphuretted hydrogen?
1. What are we told respecting the discovery of phosphorus?
2. What are its form and consistence?
3. What is the substance from which it is usually obtained?
4. Why did phosphorus remain so long undiscovered?

Phosphorus is eminently combustible: it melts and takes fire at a temperature but little exceeding one hundred degrees, and absorbs in its combustion a weight of oxygen exceeding its own nearly one half.

Caroline. What! will a pound of phosphorus consume a pound and a half of oxygen(5)?

Mrs B. So it appears from accurate experiments. I can show you with what violence it combines with oxygen, by burning some of it in that gas. We must manage the experiment in the same manner as we did the combustion of sulphur. You see that I cut the phosphorus under water, otherwise there would be some danger of its taking fire by the friction, and the heat of my fingers. I now put it into the receiver, and kindle it by means of a hot wire.

Phosphorus burnt in Oxygen Gas.

Emily. What a blaze! I can hardly look at it. I never saw any thing so brilliant. Does it not hurt your eyes, Caroline?

Caroline. Yes: but still I cannot help looking at it. A prodigious quantity of oxygen must, indeed, be absorbed, when so much light and caloric are disengaged!

Mrs B. The caloric set free in the combustion of a pound of phosphorus, would be sufficient to elevate about a hundred pounds of cold water from the common temperature to the boiling point(6).

Emily. And is the result of this combustion, like that from the burning of sulphur, an acid?

Mrs B. Yes, PHOSPHORIC ACID; similar to that contained in bones, and other parts of the animal system; and had we duly proportioned the phosphorus and the oxygen, they would have been completely converted into phosphoric acid, weighing together, in this new state, exactly the sum of their weights separately; and, on account of the vacuum formed, the water would have ascended into the receiver, and filled it entirely. In this case, as in the combustion of sulphur, the acid vapour formed is absorbed

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5. What is said respecting the oxygen absorbed in its combustion?

6. What, on the subject of burning it in oxygen gas?

and condensed in the water of the receiver. But when this combustion is performed without the presence of water, or moisture, the acid then appears in the form of concrete, whitish flakes, which, however, are extremely ready to dissolve upon the admission of the least moisture(7).

Emily. Does phosphorus, in burning in atmospheric air, produce, like sulphur, a weaker sort of acid, which you would call phosphorous acid?

Mrs B. No; for although in atmospheric air it burns less rapidly than in pure oxygen gas, it is in both cases so strongly disposed to combine with the oxygen, that the combustion is perfect, and the products similar(8). But *phosphorous acid* may be formed by the slow combustion of phosphorus, which takes place when it is simply exposed to the action of atmospheric air, at the common temperature; in which case it is believed to combine with only half the quantity of oxygen contained in phosphoric acid(9).

Emily. Is not the process in this case rather an oxidation than a combustion? For if the oxygen is too slowly absorbed for a sensible quantity of light and heat to be disengaged, it is not a true combustion.

Mrs B. The case is not as you suppose: a faint light is emitted, which is very discernible in the dark, and heat is evolved sufficient to be just sensible. A whitish vapour arises from this combustion, which, uniting with water, condenses into liquid phosphorous acid(10).

Emily. I have seen letters written and figures drawn with phosphorus, which are invisible in day-light, but may be seen in the dark by their own light. They look as if they were written, or drawn, with fire; yet they do not seem to burn.

Mrs B. But they do really burn; for it is by their slow combustion that the light is emitted, and phosphorous acid is the result of this combustion. A sheet of thick paper, or of pasteboard, may be employed for this purpose; but it is necessary to be very careful in using the stick of phosphorus, as the friction upon the paper may set fire to it, especially in warm weather(11).

Emily. Will phosphorus, like sulphur, combine with hydrogen gas?

Mrs B. Yes; and the compound gas which results from this combination produces, as it burns, a smell still more fetid than that of sulphuretted hydrogen: it is, of course, called PHOSPHURETTED HYDROGEN(12).

The *phosphuretted hydrogen gas* has this remarkable peculiarity, that it takes fire spontaneously in the atmosphere at any temperature(13). It is probable that those transient flames or flashes of light, which are sometimes seen in church-yards, and other places, and called by the vulgar *Will-with-a-Wisp*, but more properly, *Ignis fatuus*, are produced by a combination of hydrogen and phosphorus, exhaled in the putrefaction of animal matter(14).

Caroline. Country people, who are so much frightened by those appearances, would disregard them if they knew from what a simple cause they proceed. Is the procuring of phosphuretted hydrogen a difficult process?

Mrs B. No, we have the means of obtaining it very readily; the only difficulty is one which I am sure you will overcome, that of understanding the rationale of the processes by which it is formed. We can procure it by several methods; and I will show you three of them, in each of which water is

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7. What is said respecting the formation of *phosphoric acid?*
8. When burnt in atmospheric air, is phosphorous acid formed?
9. How is *phosphorous acid* produced?
10. What is said respecting its slow combustion?
11. What, of writing and drawing with it?
12. What other combination of phosphorus is noticed?
13. What peculiar property has *phosphuretted hydrogen?*
14. For what appearance is this thought to account?

decomposed in contact with phosphorus, when the *nascent* hydrogen combines with the phosphorus, and forms the gas in question.

Emily. Pray, Mrs B., what is meant by nascent hydrogen; are there two kinds of hydrogen?

Mrs B. I intended to explain this term to you, as the idea which it is designed to convey is one of great importance. Hydrogen exists in the liquid state in water, and in the solid state in most animal and vegetable, and in many mineral substances. Now, whenever it is obtained from these, and made to assume the gaseous form, there must be a moment in which this transition is taking place, and in which the hydrogen is not completely gaseous; at this moment it is in its *nascent* state. This word, so happily applied by Dr Priestley, is derived from the Latin *nascor*, to be born(15).

When a body has assumed the gaseous form, the repulsion existing among its particles will, in numerous instances, completely counteract its attraction for bodies to which it has an affinity; but the nascent state is so favourable to combination, that in passing through it many substances unite which cannot be made to do so under any other circumstances(16).

You must familiarize yourselves with this term, as it applies not only to hydrogen, but to most other bodies, and I shall therefore have frequent occasion to use it.

Caroline. It is at once so convenient and so expressive, that I am sure we shall be in no danger of forgetting or mistaking it. Sulphuretted hydrogen is, undoubtedly, thus formed, when water is decomposed by means of the sulphuret of iron and sulphuric acid.

Mrs B. Yes; and a still more striking example is afforded, by the combination of the hydrogen of sulphuretted hydrogen with the oxygen of the atmosphere, when the Harrowgate waters are exposed to its action. The sulphur I have told you separates spontaneously; and the hydrogen being then in a nascent state, combines with the oxygen, without requiring any elevation of temperature, as it would do had it fully assumed the gaseous form(17).

Emily. I wonder that the phosphorus does not decompose the water in which you keep it, as it is capable of combining with both of its constituents; but I suppose the attraction of the oxygen and hydrogen for each other is stronger than their attraction for the phosphorus(18).

Mrs B. That of course must be the cause of their remaining together unchanged; but if we put in a third substance which shall increase the tendency of the phosphorus to combine with one of the constituents of water, the decomposition may be effected(19).

Caroline. Just as the sulphuric acid, by uniting with its oxide, enabled the iron to decompose the water when you obtained hydrogen gas(20).

Mrs B. When phosphorus decomposes water, it combines with both of its constituents, forming with its hydrogen phosphuretted hydrogen, and with its oxygen phosphoric acid(21). This, like other acids, will unite with either of the alkalies and with some of the earths, and form a salt; with lime, for example, it will form a *phosphate of lime.* In some of the processes for procuring phosphuretted hydrogen, this attraction of lime for phosphoric acid may be so managed as to enable us to effect the object very readily(22).

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15. What is meant by the *nascent* state of a gas?
16. What are we told respecting its influence in combination?
17. How does sulphuretted hydrogen exemplify this fact?
18. Why does not phosphorus decompose water?
19. How may it be made to do so?
20. What analogous fact is alluded to?
21. When phosphorus decomposes water, what two compounds are formed?
22. What article may be employed to facilitate the process?

It is best in the first place to combine the lime and phosphorus together, so as to form a *phosphuret of lime.* The small auburn lumps in this phial are the substance in question. It is formed by causing phosphorus, in vapour, to pass over the lime when heated red hot; the two combine, and when cooled the phosphuret must be kept closely corked up, or the moisture of the atmosphere would quickly decompose it(23).

Emily. And is it easy to obtain phosphuretted hydrogen by means of this phosphuret of lime?

Mrs B. Nothing more is necessary than to drop a lump of it into a glass of water. Bubbles of the gas will immediately issue from it, and take fire the moment they come in contact with the air, as you perceive.

Caroline. Astonishing! that is indeed a most curious kind of gas, and although I was looking for bubbles of fire, they after all seemed to surprise me as much as though I had not expected them.

Mrs B. I think that you will very readily understand what is now taking place in the glass. The oxygen of the water is attracted by the phosphorus, unites with a portion of it, and forms phosphoric acid; this then combining with the lime, forms a *phosphate* of lime, which remains in the water. The nascent hydrogen at the same time dissolves another portion of the phosphorus, and forms the phosphuretted hydrogen, which, being a gas, escapes(24).

Emily. I can trace the operation perfectly; but had you not so clearly explained to us the rationale of the decomposition of water, and some analogous processes, which has led us gradually on, it would have appeared quite complex instead of natural and simple, as it now does.

Mrs B. I have in this retort the materials for procuring the gas, and by its aid we shall obtain larger bubbles, and exhibit their combustion more perfectly than in the experiment just shown to you. To prepare this apparatus requires some address; as the atmospheric air must be removed from the retort, and its place supplied by hydrogen, nitrogen, or some gas which will not support combustion, otherwise the bubbles would explode in the retort and blow it to pieces(25). I have placed the beak of the retort, as usual, under water, and the bubbles as they escape through it will be of considerable size.

Emily. I have not seen you put any phosphuret of lime into the retort; do you not use that material in the present instance?

Mrs B. No. The liquid is a solution of potash rendered caustic by lime, and there is in it a piece of solid phosphorus. The affinities exerted are similar to those which rendered the lime effectual in the former example. I therefore think that you will succeed in an attempt to explain the production of phosphuretted hydrogen by the mutual reaction of these substances, when gently heated together(26).

Emily. It seems to me that nothing further is necessary, in giving the explanation, than to change the term lime for that of potash. The oxygen of the water combines with a portion of the phosphorus, and forms an acid, which, as it is produced, unites to the potash, converting it into a phosphate. The nascent hydrogen dissolves another portion of the phosphorus, and escapes in the state of phosphuretted hydrogen(27).

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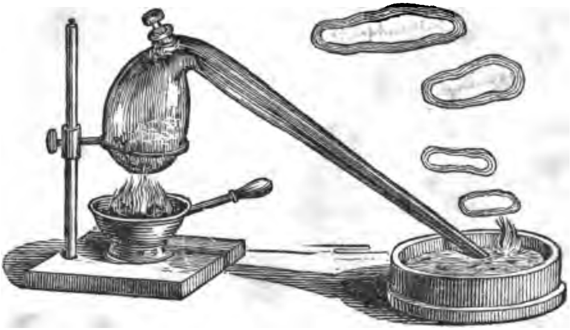
23. How is *phosphuret of lime* made?
24. What action takes place between it and water, producing phosphuretted hydrogen?
25. When prepared in a retort, what precaution is necessary?
26. What articles are put into the retort to form this gas?
27. Give the rationale of this process.

Caroline. A number of bubbles have escaped already, and yet the gas has not inflamed, but only produced a white vapour.

Emily. I saw a light distinctly in the last, and suppose the reason of their not burning before was the mixture of the phosphuretted hydrogen with the other gas contained in the retort. That last was quite bright, and the explosion very distinct.

Caroline. How beautifully and rapidly they come over now, and what a curious circular ring of smoke is formed by each, which enlarges as it ascends. From what is that effect produced?

Generation of Phosphuretted Hydrogen.



Mrs B. The hydrogen and phosphorus both unite with the oxygen of the atmosphere, the first forming water, and the last phosphoric acid. The vapour resulting from the union of the two produces the ring(28).

Emily. I should expect them to produce a vapour, but what should give to this the form of a ring I cannot conceive.

Mrs B. And perhaps I cannot satisfactorily explain it to you. I have supposed, however, that as the round bubble rises, its apex being first exposed to the atmosphere, it there first takes fire, which being rapidly propagated down through the centre, spreads out the vapour in the form you see. The smoke from the firing of cannon frequently forms such rings, and minute ones are often produced by the sputtering of a candle(29).

Caroline. Are there not some other interesting compounds of phosphorus besides those you have mentioned?

Mrs B. Phosphorus combines with a great number of substances, which we need not notice now. It may be dissolved in olive oil, and if a bottle half filled with the solution be kept closely corked, it may be preserved for years. Whenever the cork is withdrawn in the dark, the upper part of the bottle will become so luminous as to show the time by a watch. This effect arises from the slow combustion of the phosphorus, on the admission of atmospheric air. The solution may be rubbed over the face and hands with perfect safety, and when seen in the dark a curious effect is produced; the parts so rubbed being rendered luminous, whilst every other object is invisible(30).

An extremely combustible compound may be formed by the union of

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28. Of what do the vapourous rings consist?
29. What is said respecting the formation of these rings?
30. What is observed respecting phosphorus and olive oil?

phosphorus and sulphur. This *phosphuret of sulphur* is sometimes kept in small phials for the purpose of lighting matches, as small portions of it will usually take fire by mere exposure to the air. It however is a dangerous material both to make and to handle, and I therefore do not use it(31).

Emily. I think that you promised to show us another mode of making phosphuretted hydrogen; if it is not difficult we should be glad to see it.

Mrs B. It is very easy, requiring no other care than that necessary to avoid the burning of your fingers with the phosphorus.

Fountain of Fire.

Into this glass I put some small pieces of iron, or zinc, mixed with minute pieces of phosphorus, and pour water upon them. What more must I add to cause the decomposition of the water?

Caroline. Sulphuric acid, to be sure, and then the hydrogen will escape.

Emily. Yes, and I suppose the nascent hydrogen will dissolve a portion of the phosphorus, and become phosphuretted.

Mrs B. Very good. I now pour in the acid, and the effect will be immediate(32).

Caroline. What a fountain of fire! The whole surface appears to be in combustion. I am glad we have seen this experiment as it appears less complex than the others, and very clearly elucidates the formation of the gas.

EUDIOMETRY.

Mrs B. Before finally dismissing the subject of phosphorus, I will explain to you the mode of using it for the purpose of ascertaining the proportionate quantity of oxygen in the atmosphere. The art of doing this is called EUDIOMETRY, and the instruments by which it is accomplished *Eudiometers*(33). There are many methods of effecting the object in question, two of which I will now explain; they are among the most perfect, and such as you are well prepared to understand.

Caroline. I suppose that in unhealthy situations the quantity of oxygen is less than in those which are salubrious.

Mrs B. That is a very natural conclusion, but it has not been found to be correct(34). The matter of disease and of contagion, which sometimes exists in the atmosphere, is of too subtile a nature for us to detect. We know its presence by its effects, but it is a material foreign to the air, and does not effect its composition(35).

But to return to our subject; whatever substance will absorb all the oxygen, and leave the nitrogen in a confined portion of atmospheric air, will serve for eudiometry, provided this substance does not itself part with any thing to mix with the nitrogen, and alter its volume(36).

Caroline. I can very readily conceive that phosphorus may be made to accomplish this object; as either by its slow or rapid combustion in a vessel of atmospheric air, it would combine with the oxygen and leave the nitrogen behind.

Mrs B. You have a correct idea of its use. If we ignite phosphorus in

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31. What kind of compound do phosphorus and sulphur form?
32. What other mode is given for preparing phosphuretted hydrogen?
33. What is meant by *eudiometry* and *eudiometers?*
34. Is air in unhealthy situations deficient in oxygen?
35. What is said of the matter of contagion?
36. What kind of substances answer for eudiometry?

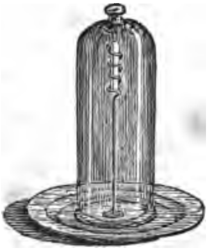
atmospheric air confined in a bell glass over water, the process will be completed in a few seconds; as all the oxygen will unite with it and form phosphoric acid, which the water will dissolve, leaving the nitrogen(37). The usual, and a better, method is to confine a stick of phosphorus in the vessel of air, and allow it to remain there two or three days, when it will have absorbed all the oxygen, and the water will consequently have risen in the glass, occupying about one fifth of its capacity, (fig. 1.) A little phosphorus, however, is in either case dissolved by the nitrogen, adding about 1-40th to its bulk, for which an allowance must be made when it is measured(38).

Emily. That is very readily comprehended. Is the other method to which you alluded equally simple?

Mrs B. Quite as much so, as it depends upon the exploding of hydrogen and atmospheric air together, and the consequent formation of water.

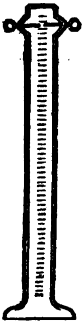
Eudiometer by the slow Combustion of Phosphorus.

Fig. 1.



Eudiometer for detonating Oxygen and Hydrogen.

Fig 2.



This is the eudiometer employed. It is a thick, tall, narrow receiver, or tube, closed at top. (Fig. 2.) Wires are inserted in two holes drilled on opposite sides near to the upper part of it. The ends of the wires within the tube approach each other, but are not allowed to touch; and if an electric spark be sent through them, it will, in passing from one to the other, set fire to any explosive mixture of the gases which may be contained within it(39).

Caroline. The use of this instrument scarcely needs further explanation; as when it contains atmospheric air and hydrogen, an explosion will unite the latter with the oxygen and form water. But if you put in a little too much hydrogen, the superabundant quantity will remain uncombined, and increase the volume of air which remains, and defeat the experiment.

Mrs B. This is really no source of error: we are careful, in fact, always to add an excess of hydrogen, in order to insure the disappearance of all the oxygen. We accurately measure the volume of the mixed gases both before and after the explosion, and thus ascertain what quantity has disappeared; and we know that exactly one-third of this quantity was the oxygen contained in the atmospheric air. By an easy calculation, therefore, we obtain our object; for merely subtracting the volume of oxygen lost from that of the

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37. How may the rapid combustion of phosphorus be used in eudiometry?
38. In what manner may its slow combustion be employed?
39. Describe the eudiometer in which hydrogen is used.

atmospheric air employed, gives the relative quantities of the oxygen and nitrogen(40).

Emily. And of course, as you know how much hydrogen you put in, you can estimate how much remains mixed with the nitrogen. The graduations on the glass must be very convenient for this purpose.

Mrs B. You are correct as respects the hydrogen, but its quantity is not an element necessary in the calculation of the quantity of oxygen. The tube is generally graduated; but sometimes the gases are measured in another very accurately divided, and kept for that purpose.

I now leave you to reflect upon the lesson of to-day, and when we meet again, recollect that our subject is to be carbon.

CONVERSATION XV.

ON CARBON AND ITS COMBINATIONS WITH OXYGEN AND HYDROGEN.

Method of obtaining pure Charcoal. Common Method of making it. Diamond. Newton's Conjecture. Insufficiency of Art to imitate many Natural Productions. Charcoal indestructible by Time, and by Heat. Antiseptic. Absorbs Gases. Carbonic Acid. Soda Water. Carbonates. Gaseous Oxide of Carbon. Carburetted Hydrogen. Obtained from Ponds. Heavy Carburetted Hydrogen, or Olefiant Gas. Davy's Safety Lamp. Naphtha.

Caroline. The substance, the nature and properties of which we are to learn to-day, is quite new to me; for although the name is familiar from its being applied to tooth powders, and other advertised articles, carbon itself I have never seen.

Mrs B. CARBON is a substance not so new to you as you imagine. It is nothing more than charcoal in a state of purity, that is to say, unmixed with any foreign ingredients(1).

Caroline. But charcoal is made by art, Mrs B., and how can a body consisting of one simple substance be fabricated?

Mrs B. You again confound the idea of making a simple body with that of separating it from a compound. The chemical processes by which a simple body is obtained in a state of purity, consist in *unmaking* the compound in which it is contained, in order to separate from it the simple substance in question. The method by which charcoal is usually obtained, is, indeed, commonly called *making* it; but, upon examination, you will find this process to consist simply in separating it from other substances with which it is found combined in nature.

Carbon forms a considerable part of many mineral substances, and also of all organized bodies; but it is most abundant in the vegetable creation, and in the state of charcoal it is chiefly obtained from wood. When the water and other evaporable constituents of the vegetable matter are volatilized at the heat of ignition, the black, porous, brittle substance that remains is charcoal(2).

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40. How is the oxygen calculated when the eudiometer with hydrogen is used?

1. What is intended by carbon?

2. Of what substances is carbon a component part?

Caroline. But if heat be applied to the wood in order to evaporate the volatile materials, will not the temperature of the charcoal be raised so as to make it burn; and if it combines with oxygen, can we any longer call it pure?

Mrs B. I was going to add, that, in this operation, the air must be excluded.

Caroline. How then can the vapour fly off?

Mrs B. In order to produce charcoal in its purest state, the operation may be performed in an iron, or earthen retort. Heat being applied to the body of the retort, the evaporable part of the wood will escape through its neck, into which no air can penetrate, as long as the heated vapour continues to rush out. And if it be wished to collect these volatile products of the wood, this can easily be done by introducing the neck of the retort into the water bath apparatus, with which you are acquainted(3). But the preparation of common charcoal, such as is used in kitchens and manufactories, is performed on a much larger scale, and by an easier and less expensive process.

Emily. I have seen the process of making charcoal. The wood is ranged on the ground in a pile of a pyramidical form, with a fire underneath. The whole is then covered with clay, a few holes only being left for the circulation of air.

Mrs B. These holes are closed as soon as the wood is fairly lighted, so that the combustion is checked, or at least continues but in a very imperfect manner; but the heat produced by it is sufficient to evaporate and force out, through the earthy cover, the greater part of the volatile principles of the wood, although it cannot reduce it to ashes(4).

Emily. Is pure carbon as black as charcoal?

Mrs B. The purest carbon we can prepare is so; but you must recollect that the colour of an article is not a test of its purity, as an alteration in the aggregation merely of the particles may affect the action of light upon it, and by this means alone its colour may be changed.

Here is a form in which charcoal appears, that I dare say will surprise you. This ring, which I wear on my finger, owes its brilliancy to a small piece of carbon.

Caroline. Surely you are jesting, Mrs B.

Emily. I thought your ring was diamond.

Mrs B. It is so. But diamond is nothing more than carbon in a crystallized state and in its purest form(5).

Emily. That is astonishing. Is it possible to see two things apparently more different than diamond and charcoal?

Caroline. It is, indeed, curious to think that we adorn ourselves with jewels of charcoal.

Mrs B. There are many other substances, consisting chiefly of carbon, that are remarkably white. Cotton, for instance, is almost wholly carbon(6).

Caroline. That, I own, I could never have imagined. But pray, Mrs B., since it is known of what substance diamond and cotton are composed, why should they not be manufactured, or imitated, by some chemical process, which would render them much cheaper, and more plentiful than the present mode of obtaining them?

Mrs B. You might as well, my dear, propose that we should make

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3. How may the purest charcoal be obtained from wood?
4. What is the common process of converting wood into charcoal?
5. What substance consists of carbon in a crystallized state?
6. What vegetable substance is nearly pure carbon?

flowers and fruit, nay, perhaps, even animals, by a chemical process; for it is known, by analysis, of what these bodies consist. But you must not suppose that a knowledge of the component parts of a body will in every case enable us to imitate it. It is much less difficult to decompose bodies, and to discover of what materials they are made, than it is to recompose them. Inorganic substances, such as water, the oxides, acids, and many others, admit of a synthetical as well as an analytical proof of their composition. To imitate many of the more complicated combinations of nature, even in the mineral kingdom, is beyond our reach, and any such attempt as regards organized bodies must ever prove fruitless. Their formation is a secret which rests with the Creator. You see, therefore, how vain it would be to endeavour to make cotton by chemical means. But, surely, we have no reason to regret our inability in this instance, when nature has so clearly pointed out a method of obtaining it in perfection and abundance(7).

Caroline. I did not imagine that the principle of life could be imitated by the aid of chemistry; but it did not appear to me absurd to suppose that chemists might accomplish a perfect imitation of inorganic substances.

Mrs B. They have succeeded in this point in a variety of instances, and, in the progress of science, methods of producing other such substances, will undoubtedly be discovered.

Emily. But diamond, since it consists of one simple, unorganized substance, might, one would think, be perfectly imitable by art.

Mrs B. It is sometimes as much beyond our power to obtain a simple body in a state of perfect purity, as it is to imitate a complicated combination: for the operations by which nature separates bodies are frequently as inimitable as those which she uses for their combination. We are ignorant of the means which nature employs to crystallize the diamond: it is probably the work of ages, to purify, arrange, and unite the particles of carbon in this form. Some chemists, it is true, have actually believed that they had succeeded in crystallizing carbon, but upon careful investigation their conclusions have been found to be incorrect(8).

Caroline. I had always supposed that the precious stones, as they are called, were all composed of earthy materials, like some of the transparent pebbles which we frequently find.

Mrs B. And, generally speaking, they are so, the diamond being the only one of the class which is combustible(9). NEWTON, the accurate observer and close reasoner, who conjectured that water contained a principle which was inflammable, being led by the same reasoning which guided him in the former instance, was of opinion that the diamond was a material wholly combustible. His discoveries in optics conducted him to this conclusion; and the fact affords a most notable example of the powerful aid which one department of science lends to another, with which, to casual observers, it may have no apparent connexion(10).

Caroline. Pray what is the reason that charcoal burns without smoke, whilst a wood fire smokes so much?

Mrs B. Because, in the conversion of wood into charcoal, nearly all the volatile particles of the former have been evaporated(11).

Caroline. Yet I have frequently seen charcoal burn with flame; therefore, it must, in that case, contain some hydrogen.

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7. What remarks are made on our power to form such substances?
8. What respecting the artificial production of diamonds?
9. Of what do the precious stones generally consist?
10. What remarkable conjecture, respecting the diamond, was formed by Newton?
11. Why is no smoke produced in the burning of charcoal?

Mrs B. You should recollect that charcoal, especially that which is used for common purposes, is not perfectly pure. It generally retains some portion of the various other component parts of vegetables, and of hydrogen particularly, which accounts for the flame in question(12). You, however, must not infer that because a body burns with flame it must necessarily contain hydrogen, as flame is simply a vapour or gas undergoing combustion. The flame of sulphur and of phosphorus is independent of hydrogen; and although most of the gases which are combustible contain this principle, it is by no means uniformly present(13).

Emily. Charcoal does not, I suppose, possess any properties which render it interesting in itself, although from its being a component part of many substances in the animal, vegetable, and mineral kingdoms, its affinities must be numerous, and its chemical history a very important one.

Mrs B. Charcoal, in the simple state in which we obtain it from wood, exhibits some very remarkable characteristics. It seems that it is altogether indestructible by age; and it appears that the ancients were aware of this fact, as the piles upon which the foundation of the temple of Ephesus rested had been charred, that is, their surfaces had been burnt to a coal. When, in modern times, some of them were taken up, the charcoal appeared perfectly fresh, and even the original marks of the axe were visible, notwithstanding the ages which had elapsed since they were driven into the ground. In Herculaneum, the manuscripts and other articles which were reduced to coal have undergone no decay. Fence posts are frequently charred by our farmers, to ensure their durability in the ground(14).

The most intense fire also produces no effect upon charcoal, if kept from contact with air, and other articles to which it has an affinity. It will, therefore, remain unconsumed and unaltered in a furnace, under melted glass or gold, for any length of time(15).

Meat may be effectually preserved from putrefaction by covering it with the powder of fresh burnt charcoal; and even after it has become tainted, the same application will effectually restore it. The most offensive ditch water may be rendered perfectly clear and sweet by filtration through a stratum of pulverized charcoal. Red wines, and most of the coloured animal and vegetable fluids, are rendered colourless by the same process, and in many instances their peculiar odours also disappear. Spirituous liquors which are *still-burnt* and otherwise badly flavoured, are frequently purified in the same way. The best filtering machines used for filtering water, owe their good properties to the charcoal which they contain(16).

Caroline. These are remarkable properties indeed, and entirely new to us. But can it be possible for carbon to unite chemically with all the offensive articles which it absorbs, for certainly it must at length become saturated?

Mrs B. This absorption of a great variety of substances by charcoal appears to depend upon its mechanical structure, and to be independent, or nearly so, of chemical affinity; as there is no evidence that any chemical combination is effected. After awhile the charcoal becomes saturated, and its power of absorption ceases, but upon heating it to redness, it again acts with the same energy as at first(17).

A still more remarkable action is exerted between charcoal and many of

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12. What causes charcoal sometimes to burn with flame?
13. Is hydrogen necessary to the production of flame?
14. What proofs are given that charcoal is indestructible by age?
15. What effect has heat upon it, when air is excluded?
16. What are its anti-putrescent properties?
17. Does this property appear to be a chemical one?

the gases. A lump of compact well burnt charcoal, will absorb, and retain within its pores, an astonishing quantity of several of them. In one instance the charcoal will absorb ninety times its own volume, that is, a cubic inch of the coal will absorb ninety cubic inches of the gas; and there are several, the absorption of which amounts to thirty volumes. Upon heating the charcoal, these gases are all given out again unchanged(18).

Emily. That indeed is a curious fact. Then, however pure charcoal may be when it is first burnt, it cannot long remain so if exposed to the atmosphere, as it will absorb a portion of whatever it finds there. But why charcoal should not change like other matter, and be decomposed by the action of air, of moisture, and of heat, is, I think, quite unaccountable.

Caroline. You forget, Emily, that it is a simple body, and therefore not liable to decomposition(19); but whilst its affinities are so numerous, I am as much puzzled as you are to tell why it should remain permanent when buried in the earth, or ignited in the fire.

Mrs B. Carbon in the form of charcoal is permanent in the earth, or when exposed to the air, at common temperatures, because, in general, it requires the heat of ignition to cause it to enter into combination with other substances. It is permanent in the fire only when kept from contact with those agents to which it has an affinity, it not being volatilized by heat(20). There are few bodies, however, which combine chemically, and manifest their attractions more readily than carbon when at a red heat.

Caroline. When charcoal is burnt, pray what becomes of the carbon itself during its combustion?

Mrs B. It gradually combines with the oxygen of the atmosphere, in the same way as do sulphur and phosphorus, and, like those substances, it is converted into a peculiar acid, which flies off in a gaseous form. There is this difference between them, however, that the acid is not, in the case of carbon, as in the two just mentioned, a mere condensable vapour, but a permanently elastic fluid, which always remains in the state of gas, under any ordinary pressure and at any natural temperature(21). It may, however, be reduced to the liquid state by strong mechanical pressure, especially when aided by a reduction of temperature. The nature of this acid was first ascertained by Dr Black, of Edinburgh; and before the introduction of the new nomenclature it was called *fixed air*. It is now distinguished by the more appropriate name of *carbonic acid*(22).

Emily. Carbon, then, can be volatilized by burning, though by heat alone, no such effect is produced?

Mrs B. Yes; but when so it is no longer simple carbon, but an acid of which carbon forms the basis. In this state, carbon retains no more appearance of solidity or corporeal form than the basis of any other gas. You may, I think, from this instance, derive a very clear idea of the bases of oxygen, hydrogen, and nitrogen gases, the existence of which, as real bodies, you seemed almost to doubt, because they were not to be obtained simply in a solid form.

Emily. That is true; we may conceive the bases of oxygen gas, and of other gases, to be solid, heavy substances, like carbon; but so much expanded by their combination with caloric as to become invisible(23).

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18. What is said respecting its power of absorbing gases?
19. Why is not charcoal capable of decomposition?
20. What is observed respecting the permanence of charcoal?
21. Into what is carbon converted by combustion?
22. Who discovered this gas, and what names has it received?
23. What illustration respecting others does this gas afford?

Caroline. But does not the carbonic acid gas partake of the blackness of charcoal?

Mrs B. Not in the least. Blackness, you know, does not appear to be essential to carbon, and it is pure carbon, and not charcoal, that we must consider as the basis of carbonic acid. We shall make some carbonic acid, and, in order to show its composition, shall burn a portion of carbon in oxygen gas.

Emily. But do you mean, then, to burn diamond?

Mrs B. Charcoal will answer the purpose still better, being softer and more easy to inflame. Besides, the experiments on diamond are rather expensive.

Caroline. But is it possible to burn diamond?

Mrs B. Yes, it is; and in order to effect this combustion, nothing more is required than to confine it in oxygen gas, and to apply a sufficient degree of heat. It was by burning diamond that its chemical nature was ascertained. Lavoisier first proved that it contained carbon, by confining it in this way, and heating it by a powerful burning-glass, by which process he obtained carbonic acid(24). With the exception of a very minute quantity of water which is produced when common charcoal is burnt, it has been found that there is no chemical difference between it and the diamond; the same quantity of oxygen combining with the same weight of either, and producing equal portions of carbonic acid, which is the only product of the combustion. On ascertaining the weight of the gas, it is found to be equal to that of the oxygen and carbon before the combustion. One hundred parts, by weight, of carbonic acid, contain about twenty-eight of carbon, and seventy-two of oxygen(25).

We will now set fire to this piece of charcoal, and suspend it in a receiver filled with oxygen gas, and although we cannot now take time to weigh or measure the materials, we shall find that after the process is completed, the oxygen will have lost its power of supporting combustion.

Emily. I am surprised that the combustion of carbon is not more brilliant; it does not give out near so much light or caloric as phosphorus, or sulphur. Yet since it combines with so much oxygen, why is not a proportionate quantity of light and heat disengaged(26)?

Mrs B. The quantity of light and heat disengaged does not depend solely upon the quantity of oxygen which enters into combination, but also upon the peculiar nature of the combustible, and of the product of combustion. Hydrogen, when burnt, exhibits but a feeble flame, yet it combines with eight times its weight of oxygen in passing into the state of water; and although the light is feeble, the heat is intense. You must not therefore expect to find the light and heat disengaged in combustion, to be in exact proportion to the oxygen absorbed. And in the combustion of charcoal, since, instead of entering into a solid or liquid combination, as it does in the phosphoric and sulphuric acids, the oxygen is employed in forming another elastic fluid, it parts with less of its caloric than when uniting to either of the former substances, the capacity of the carbonic acid gas produced being greater than that of a liquid or solid(27).

Caroline. But why should the water rise in the receiver after the combustion of carbon, since the gas within it retains its aeriform state?

Mrs B. Because the carbonic acid gas is gradually absorbed by the water; and this effect would be promoted by shaking the receiver(28).

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24. How may the diamond be burned, and what is then produced?
25. What evinces the similarity between charcoal and the diamond?
26. What is said respecting the burning of charcoal in oxygen?
27. What influences the amount of light and heat in combustion?
28. What effect has water on carbonic acid gas?

Emily. Then the water, I suppose, acquires a sour taste, and exhibits the other properties of an acid.

Mrs B. The quantity absorbed in this way would be too small to produce a very sensible effect, but by means of agitation and pressure a very large quantity may be forced in. What is usually sold under the name of soda water, but more properly called Seltzer water, contains nothing but carbonic acid, condensed by suitable machinery. Soda was formerly added, but is now usually omitted(29).

Caroline. Then the sparkling appearance and pungent taste of this water are produced by the carbonic acid gas?

Mrs B. They are; and other sparkling liquors derive this property from the same source. Carbonic acid, or fixed air, is disengaged from all vinous liquors when fermenting. Champaign, cider, porter, and many others ferment in the bottles, which being closely stopped, retain the gas until the corks are drawn(30). In the preparing of soda water for sale, the manufacturers use very strong vessels of copper, bound round with iron; and, by means of forcing pumps, the water is made to absorb a quantity of carbonic acid equal to five or six times its own bulk. Such is the elastic power of the gas when thus condensed, that notwithstanding the strength of the vessels, they not unfrequently burst; and their separated parts have been projected with a force, which has not only destroyed the lives of persons employed in charging them, but in some instances have made deep indentations even in brick walls.

Caroline. It is not surprising, therefore, that the water should be so very effervescent and sparkling when it escapes from the vessel into a tumbler; nor is it very remarkable that glass bottles should burst, when they contain within themselves a manufactory of carbonic acid.

Emily. There must be some other method of obtaining carbonic acid for impregnating soda water than that of burning charcoal in oxygen, or it would be a beverage of difficult manufacture, and of no small cost.

Mrs B. Carbonic acid, by its union with the alkalies, some of the earths, and other metallic oxides, forms a class of saline bodies, which are, of course, called carbonates. Nature furnishes these carbonates in great abundance, and by decomposing them we may obtain carbonic acid. Marble, common limestone, and chalk, are all different forms of carbonate of lime, and some one of these may be procured almost every where. The carbonic acid may be expelled from them by nearly every other acid. We generally employ the sulphuric on account of its cheapness, and not because it is better adapted to the purpose than some others(31).

Caroline. I remember seeing a mineralogist, who, in order to ascertain whether a specimen which he had was limestone, dropped upon it some acid, probably the sulphuric, and an effervescence immediately took place, the whole surface where the acid touched being covered with minute bubbles.

Mrs B. And those bubbles were undoubtedly carbonic acid. I have here some pulverized marble which I will put into a retort, and pour upon it some dilute sulphuric acid. This will combine with the lime and form with it a sulphate of lime; while the carbonic acid gas being thus set free from its combination, will escape in torrents. It is by a process similar to this that the soda water manufacturers obtain it.

Emily. How rapidly it comes over? the receiver is already filled, and the gas wasting. But it is procured so easily that the loss of a little is not of much consequence.

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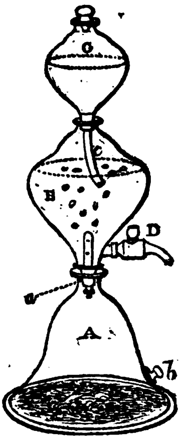
29. Of what does soda water consist?
30. What is observed respecting sparkling liquors generally?
31. With what substances is carbonic acid naturally combined?

Nooth's Apparatus.



Mrs B. Before the soda and Seltzer waters were manufactured in the large way, and introduced as common beverages, an elegant instrument, called *Nooth's apparatus*, was used for impregnating water with carbonic acid. This is the instrument upon the table. The lower vessel [A] contains some pulverized marble. The middle vessel [B] holds the water which is to be impregnated. The upper vessel [C] receives a portion of the water, when its surface is pressed upon by the gas, thus producing a reaction which promotes the absorption. These vessels fit into each other air-tight, and between the two lowest is a valve [*a*] which allows the gas to pass through it into the water, but prevents that from descending. In the lower vessel is an opening [*b*] to allow the diluted sulphuric acid to be poured upon the marble. A tube [*c*] from the upper vessel dips into the water to conduct it up into the vessel [C]. The water, when impregnated, is drawn off at the vent [D](32).

Caroline. That is, indeed, an elegant mode of exhibiting the impregnation of water with carbonic acid. I am surprised, however, at the freedom with which this water is used, as I had always understood that fixed air was very poisonous. This, however, must be an error, or it would not be thus drank with impunity.

Mrs B. When taken into the lungs in considerable quantities, it instantaneously destroys life; but though so prejudicial when breathed, it is very agreeable and salutary to the stomach. These two organs are formed for very different purposes, and must be treated according to the functions which nature has intended them to perform(33). All animals die in carbonic acid. A mouse placed in a jar of it will expire in a few seconds. I am sure, however, that you would rather be informed of this fact than have the proof of it exhibited to you. This gas also immediately extinguishes a taper, or any other burning body(34).

Emily. Yet it contains a large quantity of oxygen.

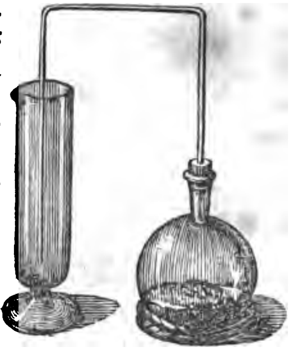
Caroline. And so does water; but it is already combined with a combustible, and therefore cannot support combustion.

Emily. You are rather rapid, my dear Caroline; I was just going to offer an explanation of the same kind myself.

Caroline. I beg your pardon, I know I was a little too quick, but was unwilling to forego the expression of a bright thought.

Mrs B. I will now collect a quantity of carbonic acid, without using the pneumatic

Carbonic Acid collected in an open Vessel.



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32. How is carbonic acid usually obtained, and what is the construction of *Nooth's* apparatus for impregnating water with it?

33. What is remarked respecting its poisonous properties?

34. Will carbonic acid support life, or combustion?

cistern, and will exhibit to you some of its properties. Into the neck of this flask, which contains the ingredients for making the gas, I insert one end of a tube, which is made to pass through a perforated cork. The tube, as you see, is bent twice at right angles, so that the other end may descend into an open mouthed glass. The gas, as it escapes, will be collected, fill the glass, and then run over the top(35).

Caroline. Why, Mrs B., you speak of it as though it were a liquid instead of a gas, and collect it as you would water from a pump.

Mrs B. It is half as heavy again as atmospheric air, and this specific gravity will enable us not only to collect it readily in this way, but actually to pour it from one vessel into another. By the aid of a little vapour which accompanies the gas, you may now see it running over, and descending below the edge of the glass(36). This lighted taper will be as completely extinguished the moment it touches the gas, as it would by immersion in water.

Emily. The smoke from the taper seems to have mixed with the gas at the surface, and forms a curious kind of little cloud.

Mrs B. By extinguishing a piece of burning paper in the same way, a large quantity of smoke will be entangled by the gas, and render the motion of it visible when I move the glass.

Caroline. That, I declare, is almost seeing the gas itself. As you move the glass backward and forward, the surface appears to be agitated like water in a high wind(37).

Mrs B. I now place a burning taper at the bottom of another glass, and by gently tilting that which contains the carbonic acid, as though we were pouring a liquid upon the taper, the gas will run out, and the taper be extinguished(38).

Emily. It no longer appears surprising that men lose their lives by descending into wells containing fixed air; and the importance of the precaution, which I have often seen published, of first letting down a lighted candle, is clearly manifest.

Caroline. The cause of such accidents is now perfectly plain, and I also perceive the source of the danger of burning charcoal in close rooms: the oxygen unites with the carbon, and produces a gas which will destroy life. What numbers might have been saved by a little knowledge of chemistry(39)!

Mrs B. There are many natural processes by which carbonic acid is produced, and you ought also to be informed that it is always contained in the atmosphere, although in very minute quantities: it has been found even on the tops of the highest mountains(40).

Emily. I wonder much at that. From its weight it might be expected to exist in low situations; but I should have supposed that if produced upon the mountains, its gravity would carry it down into the vallies.

Mrs B. Your idea is certainly a very natural one, but the law which governs other bodies in this particular does not apply to gases: when they have once become mixed, the repulsion of their particles seems to prevent their gravitating among each other. I cannot fully enter into this point, and you must be content with the information that we have no evidence

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35. How may it be collected in an open glass?
36. What is observed respecting its weight?
37. How may the motion of this gas be rendered visible?
38. State the experiment of pouring out carbonic acid.
39. What is said of fixed air in wells and in rooms?
40. What is said respecting its presence in the atmosphere?

whatever that two gases will separate merely from a difference in their specific gravities(41).

Caroline. You have not said any thing about carbonous acid, as you did of sulphurous and phosphorous. I suppose therefore that it does not exist.

Mrs B. There are several bases with which oxygen forms but one acid, and such an acid always has its termination in *ic:* this is the case with carbon. It, however, forms an oxide by combining with less oxygen than is contained in carbonic acid; this oxide is a gas, and is called *carbonic oxide,* or *gaseous oxide of carbon*(42). It contains but half the proportionate quantity of oxygen found in carbonic acid. It is inflammable, and I think that you will be able, without difficulty, to tell me what is the product of its combustion.

Emily. It must certainly be carbonic acid, as in burning it must unite with another portion of oxygen(43). This is an inflammable gas, not containing any hydrogen, such as you told us we should sometimes meet with.

Mrs B. Yes, and its history is a very curious one, as chemists had procured and experimented with it for a considerable period before its composition was detected. From its appearance in burning they took it for granted that it contained hydrogen; but as no water was produced by its combustion, the other evidences of the composition of that fluid were rendered doubtful. Few things, therefore, could have gratified the friends of what was then called the modern system, more than the discovery made by Mr Cruikshanks, of England, that the oxide of carbon was a new species of gas, containing nothing but carbon and oxygen(44).

Caroline. This gas seems to be half burnt charcoal. Can you enable us to understand any process by which it can be obtained?

Mrs B. Yes, perfectly, I think; there are several such processes, but at present one must suffice. If clean iron filings be heated to redness in a tube, and carbonic acid be made to pass through them, the filings will become oxidized by depriving the acid of a portion of its oxygen, and thus reduce it to the state of an oxide. The carbon is, as you would say, in this case, half unburnt(45).

Emily. I suppose that the class of carbonates and that of carburets are both numerous, as carbon and its acid are so extensively diffused.

Mrs B. Carbonic acid, as I have already remarked, combines with the alkalies, with several of the earths, and with the oxides of some of the metals. With carbonate of lime you have formed some acquaintance, as we have just been using it. Many of its other combinations will soon be mentioned; but I shall occupy the remainder of our time to day with the interesting class of *carburets,* and principally with the gases denominated light and heavy *carburetted hydrogen.*

Caroline. Carburetted hydrogen, like sulphuretted and phosphuretted hydrogen, must be very combustible, as both its ingredients are so. Have you any prepared, or is it easily made? I should like exceedingly to see it burnt.

Mrs B. This high gratification you enjoy every day and night of your life. The flame of our fires, of our lamps and candles, and the celebrated gas lights, are all examples of its combustion(46). Carbon and hydrogen, you already know, are constituents of nearly all animal and vegetable substances; but the resins, oils, and fats consist in great part of these two ma-

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41. What observations are made on mixed gases?
42. Does any gas but carbonic acid consist of carbon and oxygen?
43. What are its properties, and what the product of its combustion?
44. What is the history of its discovery?
45. By what process may carbonic oxide be obtained?
46. What is said respecting carburetted hydrogen?

terials. Whenever such substances are decomposed, either spontaneously or by the application of artificial heat, a new combination of their constituents takes place, and carburetted hydrogen is formed(47).

Emily. That explains the nature of flame very satisfactorily, as it consists of a gas undergoing combustion; but I do not see why a gas should continue to issue from our candles, and when once lighted, and burn until the whole of the solid matter is consumed.

Mrs B. The decomposition is commenced and continued by the same cause. Such materials as oil and tallow, when heated to redness, are decomposed, and a part of their elements assumes the form of a gas, which is highly combustible, and which if ignited in presence of oxygen will consequently burn(48). In order to light a lamp, or candle, you apply sufficient heat to decompose some of the oil or tallow contained in the wick. The gas thus produced is lighted as it escapes, and in burning continues to supply sufficient heat to keep up the decomposition(49).

Caroline. But such is not the case with the gas lights, as the gas is carried in pipes under ground, and kept ready to be lighted at any time. How is that managed?

Mrs B. We have repeatedly burnt hydrogen at the end of a tube, as rapidly as it was produced; but this same hydrogen might have been collected in a receiver, and preserved for years. If oil, tallow, resins, or resinous woods be put into a retort, or flask, and heated to redness, the gas, instead of being burnt, may be collected and preserved for future use, and this is what is done at the gas works(50).

Emily. You told us, Mrs B., that carburetted hydrogen was produced by the spontaneous decomposition of animal and vegetable matter. Now as this is every where going on, I should have supposed that a sufficient quantity of this gas would be mixed with the atmosphere, to take fire from the burning of our lamps, or from other combustions.

Mrs B. A great number of gases and vapours escape in the decay of organized substances, which, were they to continue to accumulate, would soon render the globe uninhabitable; but that kind Providence who has so wisely regulated all these operations, disposes of them so as to answer many valuable ends, some of which are within the sphere of our observation. The gases that are produced by decaying vegetables are, undoubtedly, in many instances, decomposed by those that are growing, and become part of the aliment by which they are nourished(51).

I have in this bottle a portion of the carburetted hydrogen evolved from vegetable matter. I will pass it up through water, into a receiver, and show you its combustion.

Caroline. I should like to know how to collect it, but it must require a great length of time, as vegetables decay very slowly.

Mrs B. It exists entangled in the mud at the bottom of stagnant waters. If this be stirred, bubbles of air will rise to the surface, and may be collected by filling a bottle with water, placing a funnel in its mouth, and inverting it under the surface of the pool or pond, so that the funnel may conduct the bubbles into the bottle as they rise, when the mud below is disturbed. When full, the funnel is to be withdrawn, and the bottle corked under water(52).

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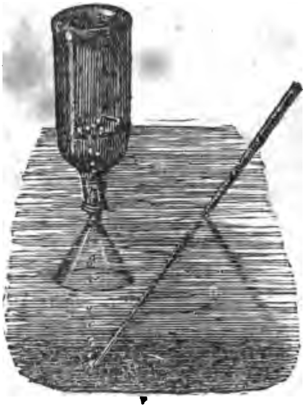
47. What substances produce this gas in abundance?
48. By what means may they be made to yield it?
49. How is it produced from our lamps and candles?
50. How is it prepared and preserved for gas lights?
51. What is said of its natural production and decomposition?
52. How may carburetted hydrogen be collected from ponds?

I filled this bottle in the manner I have described, and will now show you the combustion of the gas.

Mode of collecting Light Carburetted Hydrogen from Ponds.



Caroline. But how feebly it burns! If our lamps or candles gave no more light, they would be but poor substitutes for day-light.

Mrs B. There are, at least, two well defined species of this gas. That which you have just seen is called *light carburetted hydrogen,* and its illuminating power is very feeble; the other, called *heavy carburetted hydrogen,* burns with intense brilliancy. In most of the processes by which we obtain them, they are mixed together, and accordingly as one or the other predominates, the illumination is more or less brilliant. The heavy carburetted hydrogen appears to contain twice as much carbon, in proportion to the hydrogen, as exists in the light kind(53).

Emily. What are the two fluids, Mrs B., which you are pouring into the retort? They do not seem to agree very well together.

Mrs B. I am about to collect some heavy carburetted hydrogen. The liquid which I first poured in was alcohol, or spirits of wine, and I am now adding, cautiously, about two or three times its bulk of sulphuric acid. The mixture of these fluids sets free a large portion of caloric, and if suddenly made might break the retort.

Emily. How dark the mixed liquid appears, although the articles of which it consists were both colourless(54).

Mrs B. Before we have done with them, they will be much more dark; as what will remain of the alcohol will be merely a black charcoal.

Caroline. Charcoal in alcohol! that I never should have guessed.

Mrs B. Do you not know that every kind of spirit is distilled from vegetable materials, and must therefore be formed of some of their constituents? Alcohol, which is merely pure ardent spirit, consists of oxygen, hydrogen, and carbon; and were the two former materials removed, nothing of the alcohol would remain but black charcoal(55).

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53. What different species are there of this gas?
54. From what materials may the heavy kind be obtained?
55. What is remarked respecting the constituents of alcohol?

Caroline. Although we have seen so many examples of the transforming effect of chemical combination, the interest and the admiration, if not the surprise, which they excite remain undiminished.

Alcohol, it seems, consists of the materials of which water is formed, but with the addition of a quantity of charcoal. I think that I know some persons who would derive advantage from decomposing the alcohol which they use. They might then safely quench their thirst with one portion of it, and warm themselves by means of the other.

Mrs B. Sulphuric acid has a strong attraction for water, the constituents of which exist in the alcohol. When aided by a gentle heat, the attraction of the acid promotes their union, and water being thus formed, the alcohol is consequently decomposed. It however contains more hydrogen than enters into the composition of the water, and this excess, uniting to a part of the carbon, forms the *heavy carburetted hydrogen*, the gas which we are now collecting. We have thus disposed of the oxygen, hydrogen, and a part of the carbon, of which the alcohol consists; but a large portion of the carbon has nothing with which to combine, and remains behind in the form of charcoal, finely attenuated and perfectly black(56).

Emily. But may not the sulphuric acid contribute some part of its constituents to the formation of the gas?

Mrs B. That it does not is evident from the acid not containing either carbon or hydrogen; and besides this, the chemist is able to detect the whole of the acid after the process has been completed(57). I will now burn the gas by allowing it to issue through a tube, and then igniting it.

Caroline. What a splendid light! Well may the gas lights be more brilliant than common lamps, if they contain any large proportion of this species of air(58).

Mrs B. The name of *olefiant gas* was given to this air by its discoverers, the Dutch chemists: it was so called by them, because when mixed with an equal volume of another gas, called *chlorine*, the two condense, and form a concrete substance resembling oil. You must recollect this name, as it is still frequently used(59). All these carburetted gases are irrespirable.

Emily. As the burning of carbon produces carbonic acid, and the burning of hydrogen produces water, both must result from the combustion of this gas; and, in fact, the tallow of our candles, and the oil of our lamps, must be converted into watery vapour and fixed air(60).

Mrs B. So I was going to inform you, but am gratified at the frequent evidences of your reasoning upon, and deducing consequences from, the facts presented to you.

Do you know what this wire cage is which I have upon the table?

Caroline. I think that I have heard you call it the *safety lamp.* Is it not the contrivance which is said to be so wonderfully efficacious in preventing the explosions that take place in coal mines? Have I not also heard it called the *Davy lamp?*

Mrs B. It was invented by Sir Humphry Davy, and is universally admitted to be the source of one of the most triumphant victories which science has ever achieved by means so simple; disarming of all its terrors a power which had frequently, and in a moment, spread death and desolation around, and effecting this by the aid of a sheet of wire net-work only(61).

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56. By what action of the materials is the gas produced?
57. What is observed respecting the sulphuric acid?
58. What is noticed with regard to its combustion?
59. Why was this air named olefiant gas?
60. What is produced in the burning of our lamps and candles?
61. What is remarked respecting the safety-lamp?

In many mines carbonic acid is disengaged in large quantities, and when the miners observe that their lights burn dimly, they must retire, or be in danger of suffocation: this gas is called by them *choke damp.* In coal mines, what the miners call *fire damp,* which is light carburetted hydrogen, sometimes issues very abundantly from the fissures in the coal, and mixing with the air of the atmosphere, forms an explosive compound, which takes fire from the flame of a lamp, or candle, killing the miners, and destroying their works(62). Davy, however, ascertained that if the flame of a lamp were surrounded completely by wire gauze, the meshes of which are fine but still sufficiently open to afford a good light, it might be safely carried into the most explosive mixture(63).

Caroline. In looking at the thing, this appears so unlikely that I cannot imagine by what train of reasoning Davy arrived at such a conclusion.

Mrs B. He arrived at it by the most acute reasoning, founded upon laborious experimental investigation. Wollaston had observed that explosive mixtures would not burn in narrow tubes, and Davy, pursuing this idea, found that if the bore was very small, the tube might also be made extremely short, and still explosive gases could not be lighted through it. Now the wire gauze may be considered as formed of a great number of such tubes, the length of which is equal to the diameter of the wire(64).

Emily. Yet the gas must pass freely through these openings, and get into the lamp.

Mrs B. Certainly, and sometimes it explodes there without doing any harm: at others, the whole interior of the lamp will be filled with flame, the wire will become red-hot, and yet the gas at the outside will not be ignited.

Caroline. But what can protect the gas in the mine from being ignited [illegible]d-hot wire of the lamp? That seems incomprehensible.

Mrs B. It requires a very intense heat to set fire to the gas; and it has been ascertained that flame, although the light which it emits may be feeble, is much hotter than metal even when at a glowing red heat. A wire thus heated may be safely put into an explosive mixture, whilst a shred of paper or a single thread, burning with flame, would ignite it(65).

Caroline. That is so far satisfactory, but what can prevent the flame itself from passing through the meshes?

Mrs B. Flame can only remain such at the temperature of inflammation, and if you cool it below this, it must be extinguished. Now the wire of the lamp is a good conductor of heat, and even when red-hot is so much cooler than the flame, that the latter is extinguished in passing through it(66). This is the theory of the phenomenon as given by Davy, and although other explanations have been offered, there would be no advantage in our discussing them.

The fact that flame will not pass through a wire net may be very easily shown. Observe, I hold this piece of woven wire over a jet of burning hydrogen [fig. 1.], and the flame may, you see, be flattened down, but will not pass above the meshes, although the gas passes freely through and may be lighted above them.

I will now extinguish the flame, and hold the gauze over the tube as before, allowing the gas to pass through it [fig. 2.]. You see that I can light the gas above the wire, and yet the flame will not pass down to the tube from which it issues(67).

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62. What dangerous gases are produced in coal mines?
63. What fact did Davy discover respecting the *fire damp?*
64. What observation of Wollaston led to this discovery?
65. Why does not the heated wire produce an explosion?
66. In what way is the wire gauze believed to operate?
67. By what experiments is this illustrated?

Apparatus to show that Flame will not pass through Wire Gauze.

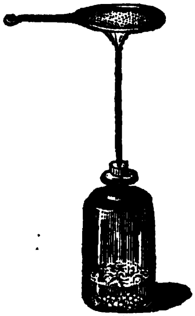

Fig. 1.

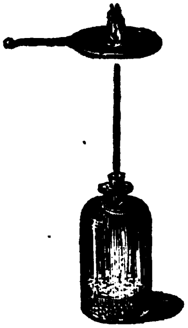

Fig. 2.

Safety Lamp.

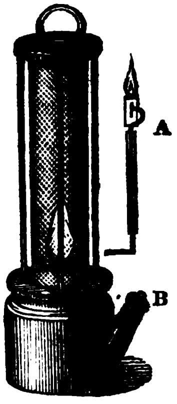

Fig. 3.

[Fig. 1. Flame depressed by wire gauze. Fig. 2. Flame prevented from descending. Fig. 3. Davy's safety lamp. A, Tube and wire which passes through the bottom for trimming it. B, Spout through which oil is supplied.]

If you examine the lamp carefully, the use of its different parts will be quite evident. The safety of the miner depends upon his not opening it, which he never has occasion to do whilst he is in the mine. There is a tube at the side of the reservoir of oil, for the purpose of supplying it; and in order to raise or lower the wick, a wire passes through a tube, which it fits exactly, and extends from the bottom to the wick(68).

Emily. This is really an interesting discovery, and there are but few things that you have explained from which I have derived equal pleasure and information.

Mrs B. There are some compounds of carbon and hydrogen that exist in the liquid form. When I exhibited potassium to you, I informed you that the liquid in which it was kept was called *naphtha*, and that it did not contain any oxygen. It is, in fact, a liquid compounded of carbon and hydrogen only, and is therefore a *carburet of hydrogen.*

Emily. Is this a natural production, or is it formed by art?

Mrs B. Naphtha is a mineral fluid which exudes from the earth in some parts of the United States, in Italy, and on the banks of the Caspian. A large quantity is, however, now obtained by distilling coal tar, which is produced at the establishments where gas is made from pit coal. It is probable that the natural and artificial productions are exactly alike in their composition: at all events they preserve potassium equally well, have the same odour, and burn with a like brilliant flame. Naphtha is nearly as light as ether, which is the lightest liquid known(69).

There is a curious compound of sulphur and carbon, which may receive a passing notice with the other carburets. Carbon and sulphur may be made to combine, and to exist in the form of a transparent and colourless liquid. This sulphuret, or rather *bisulphuret of carbon* is very inflammable,

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68. How is the safety lamp constructed?
69. What are the constituents and properties of naphtha?

acrid to the taste, and has a very offensive odour. It may be formed by passing the vapour of sulphur over fragments of red-hot charcoal. The fact of the existence of such a combination is all that would at present interest you in regard to it(70).

Our subject has detained us rather longer than usual, but you appear to have been too much interested to think of fatigue. There are some other carburets which we shall examine, but not at present. I think it necessary, instead of proceeding in a course which might be accounted more systematic, to give you some further information respecting the alkalies, and to examine the earths and metals, after which I shall explain to you the laws of chemical combination. These subjects will, I apprehend, fully occupy us for three or four meetings. I thought that you would be gratified by a knowledge of the course I intend to pursue, as it may guide you in your preparatory reading.

CONVERSATION XVI.

ON THE ALKALIES.

Distinguishing Characters of the Alkalies. Fixed and Volatile Alkalies. Potassa. Soda. Formation of Soap. Caustic and Mild Alkalies. Ammonia. Sal Ammoniac. Liquid Ammonia. Formation of Ammonia by the decomposition of Animal Matter. Carbonate of Ammonia.

Mrs B. It is no easy matter to make much progress in chemistry without acquiring some considerable knowledge of the *alkalies*; as, in consequence of their numerous combinations, we meet with them at almost every step of our journey. I have therefore thought it necessary on some previous occasions to call your attention to them, and, before we proceed further, shall give you such other particulars respecting them as may appear to me of the most importance; and should some of the facts which have been already noticed be repeated, I am not apprehensive that you will complain of their being made too familiar to you.

Emily. No, indeed, Madam; we feel very sensibly that most of them will not only bear, but, for our sakes, will need repetition; and for my own part, I am convinced that I should find more to glean in passing a second time over the same ground, than I shall have gathered in the first instance.

Mrs B. THE ALKALIES are characterized by a peculiar acrid taste, by their action upon coloured vegetable infusions, turning the blue tinctures green, and by their neutralizing the properties of the acids; with the whole of which they combine and form salts(1). Some of the earths so nearly resemble the alkalies in their properties, as to have acquired the name of alkaline earths: in fact, it is not now uncommon, in systems of chemistry, to omit placing the alkalies in a class by themselves(2). I am convinced, however, that, both in this and other instances, a departure from strict systematic rules will facilitate your course.

Formerly the alkalies were said to be three in number, POTASSA, SODA, and AMMONIA; the name of *fixed alkalies* being given to the two former, because they are not easily volatilized, whilst ammonia was denominated the *volatile alkali*, because, in its uncombined state, it exists as a gas.

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70. What combination does carbon form with sulphur?
1. By what properties are the alkalies characterized?
2. What is observed respecting some of the earths?

A third fixed alkali was discovered a few years ago; but as it has been found in very small quantities only, the mere facts of its having been named LITHIA, and of its agreement with the other fixed alkalies in being a compound of oxygen with a metallic base, comprise all that I shall say to you about it(3).

Within a few years chemists have also ascertained that the active properties of many vegetable products are in their nature alkaline. The consideration of these substances, however, will belong to vegetable chemistry, as they are the result of vegetable organization, and contain the ordinary principles of vegetable matter(4).

I think, young ladies, that you have a distinct recollection of the composition of potassa and soda.

Caroline. We recollect it perfectly, and have frequently conversed together upon the experiment of the burning of potassium upon water; its decomposing that fluid to unite with its oxygen, and thus being converted into potash. The nature of the metallic bases of potash and of soda is too intimately associated with the recollection of this experiment for us ever to forget it(5).

Mrs B. The white substance which you see in this phial is pure POTASSA. It is very difficult to preserve it in the solid state, as it is extremely deliquescent, that is, attracts the moisture from the atmosphere with great avidity; and if the air were not perfectly excluded, it would, in a very short time, be actually dissolved(6).

Emily. I suppose then that it is always found in a liquid state.

Mrs B. No: it is never found in nature in a pure uncombined state, but exists in a variety of forms and combinations. That which we procure from the shops under the name of potash, contains carbonic acid, and is, chemically speaking, a *carbonate of potash*, or of *potassa*(7).

Potash was formerly called the *vegetable* alkali, because that which is used in the arts is procured from the ashes of vegetables, and principally from wood ashes. In like manner soda was called the *mineral* alkali. These names, however, are not merely unnecessary, but improper, as each of these alkalies is found both in the vegetable and mineral kingdoms(8).

Caroline. I observe that you use the terms *potash* and *potassa* to designate the same substance: ought we not to restrict ourselves to one of them?

Mrs B. They are frequently used indiscriminately, as perfect synonymes; but by potash is generally intended the impure alkali as we find it in commerce, and by potassa, the pure substance, separated from all foreign matter. We shall not, however, strictly confine ourselves to these distinctions(9).

Emily. As potash is contained in vegetables, and is so very soluble, I suppose it can be separated by soaking them in water.

Mrs B. We are not very well informed of the state in which potash exists in most vegetables; for although some of its salts can be obtained from the juices of certain plants, it is usually so intimately combined with the other vegetable constituents, as not to be capable of separation until they are decomposed by burning, when its fixed nature causes it to remain behind after all the volatile ingredients are separated. The alkali has a strong affinity for carbonic acid, and therefore combines with a portion of that which is produced

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3. Name the alkalies, and the manner of designating them.
4. What other alkaline substances have been discovered?
5. Of what are potassa and soda composed?
6. What effect has the atmosphere on potassa?
7. What is the nature of the potash of commerce?
8. How were potash and soda formerly distinguished?
9 What is observed respecting the terms potash and potassa?

by the combustion of the carbon of the wood, and hence it is always first obtained in the form of a carbonate(10).

Caroline. Of what ingredients do the ashes of burnt vegetables consist?

Mrs B. The insoluble parts principally consist of some of the earths and metallic oxides; and the soluble ingredients are the carbonate of potash, and small portions of some other saline substances(11). By pouring water upon the ashes, the salts are dissolved, whilst the insoluble portion of the ashes remains at the bottom of the vessel. The solution is then put into iron pots, and the water boiled away. When the evaporation is completed, the carbonate of potash, mixed with the other salts, is obtained in a dry state, and forms the potash of the shops, which undoubtedly derived its name from the pots in which it is prepared(12).

Pearlash is the same substance, partially purified. It is also sold under the names of *salt of tartar* and *salt of wormwood;* but in this case it is usually still further purified from the foreign salts(13).

Emily. Still, neither of these is potassa: they are carbonates, and of course we cannot examine the properties of the pure article when combined with an acid. In what way can it be deprived of its carbonic acid?

Mrs B. Lime has a strong affinity for carbonic acid, and will separate it from potash. For this purpose we take *quicklime*, that is, lime which has been deprived of its carbonic acid. This we mix with a solution of potash, and heat the mixture; a carbonate of lime will then be formed and precipitated, whilst the *caustic potash* will remain in the liquid, and may be obtained in the solid state by evaporation(14).

Caroline. Now I understand the use of lime when soft soap is made, and perceive how it sharpens the ley, as the servants say. The water which soaks through the wood ashes, and forms the ley, becomes charged with potash, or rather is a solution of the carbonate of potash; and the addition of quicklime removes the carbonic acid, renders the ley caustic, and accelerates the formation of the soap(15).

Mrs B. You will soon, I hope, make a good housewife, and be able to superintend the process which you have so well described. Potash and soda both form soap when combined with fat, or oils; the former producing soft, and the latter hard soap. To cause them to combine with the fatty matter, it is proper to render them caustic; as their combination with an acid would interfere with their tendency to unite with any other article(16). Some curious information with respect to the chemical composition of soap I must reserve until we have examined the nature of animal and vegetable oils.

Caroline. By the *mild* alkali which you mentioned, it appears that the carbonate is intended, and by the *caustic*, the alkali deprived of its carbonic acid?

Mrs B. Yes, but these are considered as old names. They are, however, so expressive of the difference in the two states of the alkali, that they are not unfrequently used, and are not likely to be entirely dismissed. The caustic alkali rapidly corrodes the skin and the flesh, converting them into

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10. What is said of the combination of potash with the other vegetable constituents, and of its conversion into a carbonate?
11. What articles are contained in the ashes of vegetables?
12. How is the potash separated, and why is it so named?
13. By what other names is it known?
14. How may it be separated from the carbonic acid?
15. What does Caroline remark concerning the making of soap?
16. What constitutes the difference between hard and soft soap?

a soapy substance. When mixed with lime, it is used by surgeons as a caustic, under the name of *lapis infernalis*(17).

With potassa we have yet much to do, as it not only combines with all the acids, forming a very great number of different salts, but it is also an ingredient in many other natural and artificial compounds, and particularly in that beautiful material, glass, which is produced by simply fusing common sand with potash, or with soda(18).

Emily. What an extremely useful substance is potash! I feel curious to hear something more respecting the employment of it in making glass.

Mrs B. You will soon be gratified in this particular, but not until after we have examined the earths that are concerned in making it.

We must now proceed to SODA, which, however important, will detain us but a very short time, as, in all its general properties, it very strongly resembles potash. Indeed, so great is their similitude, that they were long confounded, and they can now scarcely be distinguished, except by the difference of the salts which they form with acids.

The great source of this alkali is the sea, where, combined with a peculiar acid, it forms the salt with which the waters of the ocean are so strongly impregnated.

Emily. Is not that the common table salt?

Mrs B. The very same; but we must postpone entering into the particulars of this interesting combination, as you are not yet acquainted with its constituents. Soda may be obtained from common salt; but the usual method of procuring it is by the combustion of marine plants, an operation perfectly analogous to that by which potash is obtained from land vegetables(19).

Emily. From what does soda derive its name ?

Mrs B. From a plant called by us *soda*, and by the Arabs *kali*, which affords it in great abundance. Kali has, indeed, given its name to the alkalies in general.

Caroline. If potassa and soda resemble each other so nearly, may they not be really, as was formerly supposed, the same substance, only modified by some particular circumstances not well understood?

Mrs B. Neither you nor I are justified in making such a conjecture. The able chemists who have devoted their lives, not to guessing, but to experiments of research in their laboratories, must not only be allowed, but have a right to decide questions of this sort for those who are only chemists of the parlour. Have you forgotten the fact of the decomposition of these alkalies, and the difference in the properties of *potassium* and *sodium*? If these are different, as they are the bases of the substances in question, all their combinations must necessarily be so likewise. The saline bodies, formed by the combinations of each of these alkalies with the same acid, you will, in general, find to be very plainly marked with distinctive characters(20).

Caroline. I confess, madam, that your mild rebuke was well merited: So young a chemist as I am, or rather a mere novice in the science like myself, may well be satisfied to listen and inquire, without offering her own crude conjectures.

Mrs B. AMMONIA, or the VOLATILE ALKALI, must now receive some attention.

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17. What is said concerning the caustic and the mild alkalies?
18. What combinations are formed with the fixed alkalies?
19. Whence is soda principally obtained, and what is said respecting it?
20. By what is the difference between potash and soda proved?

Emily. I long to hear something of this alkali; is it not of the same nature as hartshorn?

Mrs B. Yes, it is, as you will see by-and-by. This alkali, being a gas, is not found in nature in its pure state. It was formerly extracted, exclusively, from a salt, called *sal ammoniac*, which was imported from Ammonia, a region of Lybia, from which country the salt and the alkali both derive their names. Some of the salt is contained in this bottle; it consists of a combination of ammonia and muriatic acid(21).

Caroline. Then it should be called *muriate of ammonia*; for though I am ignorant what muriatic acid is, yet I know that its combination with ammonia cannot but be so called, and I am surprised to see *sal ammoniac* inscribed on the label.

Mrs B. That is the name by which it has been so long known, that the modern chemists have not yet succeeded in banishing it altogether. It is still so denominated by druggists, though by scientific chemists it is more properly called muriate of ammonia.

Emily. And how is the alkali separated from this salt, so as to obtain it in the gaseous state?

Mrs B. By the same substance which separates carbonic acid from the carbonate of potassa.

If equal parts of dry, slaked, quicklime and muriate of ammonia be mixed together, and put into a retort, on applying heat the gaseous or volatile ammonia will be expelled.

Emily. Then, as the carbonic acid united with the lime in the case of potassa, so, in the present instance, what you call muriatic acid must do the same, and a muriate of lime be formed(22).

Mrs B. Your conjecture, or rather your judgment, is correct in this particular; and I am happy to find you so well prepared to trace some of those more complex operations of chemistry to which your attention will soon be called.

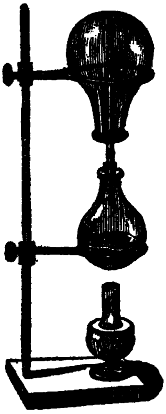
Emily. Cannot we collect some of this gaseous ammonia by means of the pneumatic cistern?

Mrs B. That would be impossible, unless we were to keep the water highly heated, as water at common temperatures absorbs this gas very rapidly. If kept cold by ice, it will condense about 700 times its own bulk. Water, when impregnated with this gas, is called *liquid ammonia, aqua ammoniæ*, or *spirits of hartshorn*(23).

For collecting the gases which are readily absorbed by water, the chemist uses a cistern and receivers, filled with mercury; but although I am not provided with this apparatus, we can contrive to collect some of the gas, as we formerly collected hydrogen, in consequence of the difference between its specific gravity and that of atmospheric air. The principle upon which this operation depends you very well understand(24).

Caroline. From the manner in which you have fixed the apparatus, this gas, like hydrogen, must be lighter than the air of the atmosphere. The materials

Gaseous Ammonia collected in an open Flask.



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21. What is *ammonia*, and why was it so named?
22. How is it separated from muriate of ammonia?
23. What is remarked of its absorption by water?
24. In what way is this gas usually collected?

which produce it are contained in the lower vessel. From these, the heat will disengage it, and its levity will cause it to ascend through the tube into the flask above, where gradually accumulating, it will force out the common air and occupy its place(25).

Emily. I already smell its pungent odour, just like that of hartshorn, or of the volatile smelling salts, which, when not too strong, I think very agreeable.

Mrs B. If we now remove the flask carefully, and immerse its mouth in water, the liquid will rapidly ascend, and, were no common air mixed with the ammonia, the water would completely fill the glass.

Emily. Certainly; because the water will absorb the gas, and the pressure of the atmosphere will force it up to fill the vacuum which would otherwise be formed by this absorption(26).

Pray is ammonia similar in its composition to the fixed alkalies?

Mrs B. Gaseous ammonia was first obtained by Dr Priestley, but its composition was ascertained by the celebrated French chemist Berthollet, who discovered that it consists of about one part of nitrogen combined with three parts of hydrogen. He decomposed it by confining a portion of the gas over mercury, and causing a succession of electrical sparks to pass through it: he found that when thus treated, it increased in bulk, lost all its odour and its alkaline properties, and was actually converted into a mere mixture of nitrogen and hydrogen gases. The latest and most accurate experiments have confirmed this fact, and prove that when these gases combine to form ammonia, they are condensed into one-half their previous volume; that is, could we cause one pint of nitrogen to combine with three of hydrogen, they would produce but two pints of ammonia. They do not unite, however, unless one or both of the gases is in a nascent state(27).

Caroline. Has the chemist discovered the mode of manufacturing ammonia by causing its constituents to combine? I conclude that this is the case, from your mentioning whence it was *formerly* procured.

Mrs B. Nearly the whole of what is now used in chemistry and the arts is produced by the combination of its elements. When animal substances are decomposed, either spontaneously or by art, among the numerous products which are formed, ammoniacal gas results from the combination of portions of their nitrogen and hydrogen with each other.

Bones, or other solid animal matter, are put into large iron retorts. These are heated to redness, and the volatile products conducted through tubes into water, where those of them which are susceptible of it are condensed. Among these is ammonia in a very impure state, and combined with the acid products of the decomposition, but capable, by proper agents, of being separated from them and applied to use(28).

Emily. Is the volatile alkali equally caustic with the fixed?

Mrs B. Potash and soda themselves are not alike in this respect, the former being the most caustic; but it is difficult to compare them with ammonia, which is a gas. This gaseous alkali, however, irritates the skin very much, especially when it touches the eyes, or passes into the nostrils undiluted; and there appears reason to believe that if it existed in a solid state, its caustic action would be, at least, as powerful as that of potash(29).

You have seen one salt, muriate of ammonia, in which this alkali and the acid exist in the solid form, and yet both of its constituents are gaseous.

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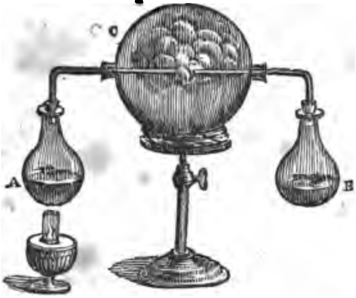
25. How may it be obtained without a mercurial trough?
26. What experiment is mentioned showing its absorption by water?
27. What is its composition, and how was this ascertained?
28. By what process is ammonia now manufactured?
29. What is said respecting the causticity of ammonia?

The same is the case with the *carbonate of ammonia*, or volatile smelling salts, an article with which you are familiar. Whenever the two gases, carbonic acid and ammonia, come into contact with each other, they combine and become solid(30).

The tubes from these two flasks pass into the same receiver. From one of them issues carbonic acid, from the other ammonia; and the white cloud which fills the receiver is the salt in question. This cloud will soon condense and form an incrustation upon the inside of the glass(31).

Formation of Carbonate of Ammonia.



[A. Flask containing quicklime and sal ammoniac. B. Flask with carbonate of lime and sulphuric acid. C. The globe into which the two gases are conducted and in which they combine together.]

Caroline. This last experiment is equally pleasing and satisfactory, as it affords an interesting example of the change of form produced by chemical combination, and gives us some new information respecting an old acquaintance.

Mrs B. A short summary of the properties of ammonia is all that time will allow me to add, after which we must dismiss it with the certainty of meeting it again in other company.*

Ammonia is irrespirable; an animal immersed in it being immediately killed. It extinguishes burning bodies, neither of its constituents being supporters of combustion. It is itself combustible, as it will burn, although but feebly, when ignited in contact with atmospheric air; its hydrogen uniting to the oxygen of the atmosphere and forming water, leaving its nitrogen free. Combining with the acids, it becomes the base of a large number of salts. By powerful pressure, assisted by cold, it can be condensed into the liquid form(32).

To-morrow we will occupy ourselves with an inquiry into the nature of the earths, several of which, in their properties, are nearly allied to the fixed alkalies, and in their composition are known to be analogous to potassa, soda, and lithia.

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30. What is said of the combination of ammonia and carbonic acid?
31. By what means may the carbonate of ammonia be collected?
32. Give a summary of the properties of ammonia.

CONVERSATION XVII.

ON THE EARTHS AND SOME OF THEIR COMBINATIONS, AND ON METEORIC STONES.

Alkaline Earths. Lime. Quicklime. Slaked Lime. Lime-water. Carbonate and Sulphate of Lime. Lime as a Manure. Calcium. Baryta, or Barytes. Strontia. Barium and Strontium. Magnesia. Carbonate and Sulphate of Magnesia. Magnesium. Silex. Glass. Vitrification of Earths. Enamels. Silicon. Alumina, or Argil. Pottery. Earthenware and Porcelain. Aluminum. Zirconia. Glucina, Yttria and Thorina. Meteoric Stones.

Mrs B. THE EARTHS are ten in number. By some chemists three, but more frequently four of them, are called alkaline earths, because they possess so many properties in common with the fixed alkalies. The four to which I allude are *lime*, *baryta* or *barytes*, *strontia* or *strontites*, and *magnesia*. The other five are named *silica* or *silex*, *alumina* or *alumine*, *zirconia* or *zircon*, *glucina* or *glucine*, and *yttria*(1).

Emily. What we usually term earth, consists of matter, which when dry is in fine powder; but I understand that, chemically speaking, the state of aggregation is disregarded, and that rocks and stones are considered as earths, just as much as sand and clay.

Mrs B. To attempt to define what is meant by the earths is unnecessary, and would rather embarrass than aid us; as the different properties by which they are distinguished are not possessed in the same degree by the whole class.

The substances which we term earths, constitute the greatest part of the solid crust of the globe, and they are of peculiar interest, not only from their abundance, but from their extensive use in the arts. Of the ten which I have named, three, *glucina*, *zirconia*, and *yttria*, are very rarely found, and two others, *baryta* and *strontia*, are scarcely employed excepting as chemical agents; so that, as regards the arts, four only are of much interest, namely, *lime*, *magnesia*, *silica*, and *alumina*(2).

Rocks and stones generally consist of two or more of these earths, and often contain some metallic matter. When we obtain the earths in a state of the greatest purity, they are in the form of a dry white powder, without smell, and, most of them, without taste. Some are sparingly soluble, and others insoluble in water. They are all incombustible, being, like the alkalies, products of combustion. Most of them are known to be formed of metallic bases combined with oxygen(3).

Caroline. The soil of our fields and gardens appears then to consist of some of these earths in powder, mixed with decayed animal and vegetable matter, to which, of course, it owes its fertility.

Mrs B. The earths form the solid basis of the soil, and enter, though sparingly, into the composition of the animals and vegetables which exist on its surface. The latter of these, however, as you justly observe, derive

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1. Name the earths, distinguishing those called alkaline.
2. What general remarks are made concerning them?
3. What is the constitution of the earths, and what is said of rocks and stones?

their principal nutriment from the same materials which had previously entered into the constitution of organized beings(4).

Placing the alkaline earths the first upon the list, we will now inquire into the properties of *lime*.

LIME is strongly alkaline. In nature it is not met with in its simple state, but united either with other earths, or with acids. Its affinity for water and carbonic acid is so great, that it is most commonly found combined with these substances, with which it forms the common lime-stone; but whenever a sufficient degree of heat is applied, it is separated from these ingredients, which are volatilized. What is called burning of lime, is merely heating it red-hot in a kiln, in order to drive off these ingredients, which amount to half the original weight of the stone(5).

Emily. *Quicklime*, then, is nothing but lime-stone, which has been deprived, in the kiln, of its water and carbonic acid?

Mrs B. Precisely. *Quicklime* is so caustic, that it is capable of decomposing the dead bodies of animals very rapidly, without their undergoing the process of putrefaction. I have here a lump of quicklime recently prepared, for had it been long exposed to the atmosphere, it would have absorbed moisture from it, and have become *slaked.* Here is also some common unburnt lime-stone—we will pour a little water on each, and observe the effects which result from it.

Caroline. How the quicklime hisses! It has become excessively hot!—It swells, and now it bursts and crumbles into powder, while the water appears to produce no kind of alteration on the lime-stone(6).

Mrs B. Because the lime-stone is already saturated with water, whilst the quicklime, which has been deprived of it in the kiln, combines with it with very great avidity, and produces that great disengagement of heat, the cause of which I formerly explained to you: do you recollect it?

Emily. Yes; you said that the heat did not proceed from the lime, but from the water, which was *solidified*, and consequently parted with its latent heat.

Mrs B. Very well. If we continue to add successive quantities of water to the lime, after being slaked and crumbled, as you see, it will then gradually be diffused in the water, and form a pasty mass. Were we to continue to add water, the lime would at length be dissolved in it, and entirely disappear; but for this purpose it requires no less than 700 times its weight of water. This solution is called *lime-water*(7).

Caroline. How very small, then, is the proportion of lime dissolved!

Mrs B. The liquid contained in this bottle is lime-water: it is often used as a medicine, chiefly, I believe, for the purpose of combining with, and neutralizing, the superabundant acid which it meets with in the stomach.

Emily. I am surprised that it is so perfectly clear: it does not at all partake of the whiteness of the lime.

Mrs B. Have you forgotten that, in solutions, the solid body is so minutely subdivided by the fluid as to become invisible, and, therefore, will not, in the least degree, impair the transparency of the solvent?

The attraction of lime for carbonic acid is so strong, that it will absorb it from the atmosphere. We may see this effect by exposing a glass of lime-water to the air: the lime will soon separate from the water, and form a white film upon the surface, which is *carbonate of lime*, and perfectly similar to common *chalk*(8).

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4. Of what are the earths said to form constituent parts?
5. What is observed on the subject of *lime* and its carbonate?
6. What is meant by quicklime, and what effect does water produce upon it?
7. If more water is added, what would eventually occur?
8. What is lime-water, and what effect has air upon it?

Caroline. The white film begins already to appear on the surface of the water; but it is far from resembling hard solid chalk.

Mrs B. That is owing to its extreme tenuity: in a little time it will collect into a more compact mass, when, upon the slightest agitation, the film will break and subside to the bottom of the glass.

If you breathe through lime-water, the carbonic acid, which is mixed with the air that you expire, will produce a similar effect. It is an experiment very easily made:—I will pour some lime-water into this wine-glass, and, by breathing repeatedly through it by means of a glass tube, you will soon perceive a milky appearance in the water, and a precipitation of carbonate of lime.

Emily. I see already a small white cloud formed.

Mrs B. It is composed of minute particles of chalk: these at present float in the water, but they will soon subside(9).

Carbonate of lime, you see, is insoluble in water, since the lime which was dissolved reappears when converted into a carbonate; but you must take notice of a very singular circumstance, which is, that chalk is soluble in water highly impregnated with carbonic acid.

Caroline. It is very curious, indeed, that carbonic acid gas should render lime soluble in one instance, and insoluble in the other!

Mrs B. I have here a bottle of soda water, which, you know, is strongly impregnated with carbonic acid; let us pour a little of it into a glass of lime-water. You see that it immediately produces a precipitation of carbonate of lime.

Emily. Yes, a white cloud appears.

Mrs B. I will now pour an additional quantity of the soda water into the lime-water.—

Emily. How singular! The cloud is re-dissolved, and the liquid is again transparent(10).

Mrs B. The mystery will disappear, if it be admitted that the carbonate of lime is soluble in carbonic acid, whilst it is insoluble in water. The first portion of carbonic acid, which I introduced into the lime-water, was all employed in forming the carbonate, and of course there was none left to dissolve it, but an additional quantity of carbonic acid effected its solution(11).

Caroline. That is easily understood, and quite satisfactory. You formerly mentioned that marble was a species of lime-stone, and I know that, in some places, it is burnt in kilns to make quicklime. I have likewise seen oyster-shells used for the same purpose: are they too carbonate of lime?

Mrs B. They, and the shells of other fishes, consist principally of carbonate of lime, but also contain phosphate of lime: they are therefore less pure, and make a weaker mortar than most of the lime-stones(12). You are aware that the mortar and plaster used in building consist of quicklime and sand. These two substances gradually harden, and, in the lapse of years, become like stone. It is for this reason that the mortar is extremely hard in old buildings: in them the lime has gradually been reconverted into a carbonate by absorbing the carbonic acid of the atmosphere(13).

Emily. Is not *plaster of Paris* a kind of lime? I know it is used with water much in the same way, when the plaster figures are made of it.

Mrs B. Plaster of Paris is a *sulphate of lime,* which is found in great abundance in many places. The city of Paris is almost entirely built of,

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9. Detail the experiment of breathing through lime water.
10. What is the fact respecting the solubility of carbonate of lime?
11. In what way is this accounted for?
12. What is said respecting marble and the shells of fishes?
13. What occasions the hardness of mortar in old buildings?

and founded upon it, and from that place it has derived its most common name, but it is also called *gypsum*. In preparing it to be used as a cement, or mortar, or for making plaster casts, it is heated, which separates a quantity of water from it, but does not drive off its acid. When this *calcined plaster*, as it is called, is mixed up with a quantity of water sufficient to give it the consistence of cream, it may be poured into moulds, and will harden into a kind of stone in a very few minutes(14).

Caroline. But what becomes of all the water in this case; it cannot dry so rapidly?

Mrs B. Do you not recollect the fact as regards lime, that water combines with it, forms a *hydrate*, and becomes solid? Such is the case with the sulphate of lime; there is a true chemical combination between it and the water, just as there is in lime-stone, and in a large number of other solids(15).

Emily. Are the carbonic and sulphuric acids the only ones with which lime is naturally combined in the earth?

Mrs B. No, but there is only one other, which we shall examine, and that not at present; it is the beautiful *Derbyshire* spar, which is a *fluate of lime*. This and some other combinations of lime remain to be noticed in their proper places.

Caroline. I have seen lime, oyster shells, and plaster of Paris spread over the land to render it fertile. In what way do they operate?

Mrs B. Quicklime, the carbonate, and the sulphate of lime, are each employed as manures. The former is supposed to render active the inert vegetable matter which may be in the soil, by promoting its decomposition; the two latter appear to stimulate the plants, as they enter into their substance, and can be detected in them by chemical analysis. We, however, are much better acquainted with the *fact* of their promoting vegetation, than we are with the *cause* of their doing so(16).

Caroline. I am not quite certain, but I believe you informed us that lime had been decomposed.

Mrs B. It has; and it yielded oxygen, and a white metal with the lustre of silver, to which has been given the name of CALCIUM, lime itself being known by that of *calcareous earth*. This metal has been obtained in very small quantities only, and cannot be preserved, as its affinity for oxygen causes it to combine with it very rapidly when exposed to the atmosphere, and thereby to reproduce *oxide of calcium*, that is, quicklime(17).

I shall now say a few words about *baryta*, or *barytes* as it is more frequently called.

Emily. May I not repeat the question put by Caroline, when you were treating of the alkalies, and ask, if it would not be better to reject one of the names which you have mentioned, so as to preserve uniformity in this respect?

Mrs B. The attempts at producing uniformity, have actually introduced diversity, as names long used are not easily changed. It has been thought that the names of the alkalies and earths ought to have a similar termination, and that in *a*, has been preferred: hence *potassa*, for *potash; baryta* for *barytes;* and so of all the others, with the exception of lime, which would not conform to this arrangement without offering too great violence to a word so familiar. As this termination in *a* is not uniformly followed, I shall occasionally use the more common, as well as the more systematic names(18).

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14. What is plaster of Paris, and how is it prepared and used?
15. What becomes of the water with which it is mixed?
16. What is said of the use of lime as a manure?
17. Has lime been decomposed, and of what does it consist?
18. What is said of the nomenclature of the earths?

Barytes is very nearly allied to lime in its properties. In the form of a sulphate it is a pretty abundant mineral; in that of a carbonate it is but sparingly diffused. It is remarkable for its great weight, which acquired for it its former name of *terra ponderosa*, or heavy earth.

It can be rendered caustic, and will slake like lime; but is much more soluble than that earth, water taking up about one twentieth of its own weight. Its solution, and that of its salts are virulent poisons(19).

Barytic water, that is a solution of baryta in water, is kept as a test by the chemist. It forms an insoluble salt with carbonic acid, and has so strong an affinity for it that it will separate it from nearly all its combinations. A drop of this water when let fall into a carbonate in solution will instantaneously produce a white cloud of carbonate of barytes(20).

Another alkaline earth was discovered some years ago, at a place called Strontian, in Scotland, whence it is called **strontia**, or **strontites**. It so strongly resembles barytes in its properties, is so sparingly found in nature, and of so little use in the arts, that it will not be necessary to enter into any particulars respecting it. One of the remarkable characteristic properties of strontites is, that its salts, when dissolved in spirit of wine, and the liquid set on fire, communicate to the flame a tinge of a deep red, or blood colour. In its native state it exists either as a sulphate, or a carbonate. It is poisonous, but less so than barytes(21).

Both baryta and strontia have been made to yield metallic bases, respectively called **barium**, and **strontium**. Both greedily absorb oxygen and return to the state of oxides(22).

Caroline. I confess, Mrs B., that I do not find the history of the earths half so entertaining as that of the simple substances, and their combinations.

Mrs B. I presume not, but recollect that the beneficial object of our meeting is not entertainment, but instruction; and that however desirable it may be to combine the two, the latter must never be sacrificed to the former. The earths form the basis of so many interesting and important compounds, that to omit them would be to leave a veil over other parts of the science of chemistry, which would render them completely obscure.

The next earth to be considered is **magnesia**.

Caroline. I am already pretty well acquainted with that earth, from its use as a medicine.

Mrs B. It is employed medicinally both in the state of a carbonate, and in that usually called *calcined magnesia*. It is then, in fact, simple magnesia; the water and carbonic acid having been driven off from the carbonate by heat. This earth is very insoluble, requiring 2000 times its weight of water to dissolve it; but with most acids it forms extremely soluble salts. It has not so great an attraction for acids as lime has, and consequently yields them to the latter. It is found in a great variety of mineral combinations, such as slate, mica, amianthus, soap-stone, and in certain lime-stones, to which it imparts peculiar qualities. It does not, like lime, attract and solidify water; but when mixed with water and exposed to the atmosphere, it slowly absorbs carbonic acid from the latter, and is thus reconverted into a carbonate. Its chief use in medicine is, like that of lime, derived from its readiness to combine with, and neutralize, the acid which it meets with in the stomach(23).

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19. What is the nature, and what the properties of *barytes*?
20. Of what is barytic water a delicate test?
21. What other earth strongly resembles baryta?
22. What is the constitution of these two earths?
23. What is said of *magnesia* and its properties?

Emily. Yet, you said that it was frequently taken in the state of carbonate, in which case it is already united with an acid; how then can it neutralize the acid in the stomach?

Mrs B. Because the carbonic acid stands so low in the order of affinities, that it will yield the magnesia to any of the others. It is, however, now most commonly taken in its calcined state; as it is not, like lime, rendered caustic by calcination. Combined with sulphuric acid, magnesia forms another and more powerful medicine, commonly called *Epsom salt.*

Caroline. And properly, *sulphate of magnesia.* Pray, how did it obtain the name of Epsom salt?

Mrs B. Because there is a spring in the neighbourhood of Epsom, in England, which contains this salt in great abundance, and from which it was originally procured. It is now, however, extensively manufactured from minerals which contain magnesia; and also from the water of the ocean, in which it is always found(24).

Magnesia is decomposed with difficulty, but Sir Humphry Davy succeeded in procuring a minute portion of its base, which exhibited metallic properties, and received the name of *Magnesium.*

You are aware, I believe, of what the chemist means by SILICA, or SILEX.

Caroline. I understand the term *silex,* to be synonymous with *sand;* but still it does not seem that sand can be a pure, individual earth, as any pulverized hard stone would assume the appearance of sand.

Mrs B. Although what is commonly called sand is not pure silex, yet that which is found in the beds of our rivers, and on the sea shore, is nearly so. The other earths, being lighter, are washed out from the silex; or from being, to a certain extent, soluble in water, are gradually dissolved(25).

Silex, or *Silica,* abounds in rock-crystal, flint, sand, sand-stone, agate, jasper, cornelian, and many other minerals, and it forms the basis of some of the precious stones. It is rough to the touch, and so hard that it scratches and wears away glass, metals, and stones. It is not soluble in water, nor is it acted upon by any acid excepting the *fluoric*(26).

Emily. Pray what is the true colour of silex, which forms such a variety of different coloured substances? Sand is brown, flint is nearly black, and precious stones are of all colours.

Mrs B. Pure silex, such as is found only in the chemist's laboratory, is, like the other earths, perfectly white; and the various colours which it assumes in the different substances you have just mentioned, proceed from the different ingredients with which it is combined in their formation.

Caroline. I wonder that silex is not more valuable, since it forms the basis of some of the precious stones.

Mrs B. You must not forget that the value we set upon precious stones depends in a great measure upon their rarity; for, were those productions either common, or perfectly imitable by art, they would no longer, notwithstanding their beauty, be so highly esteemed. But the real value of silicious earth, in many of the most useful arts, is very extensive. Mixed with clay, it forms the basis of all the various kinds of earthenware, from the most common utensils, to the most refined ornaments of china or porcelain.

Emily. And we must recollect its importance in the formation of glass with potash and with soda, which you incidently mentioned; and likewise its use in giving hardness to mortar, and other cements(27). I hope that

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24. What is *Epsom salt,* and how is it procured?
25. What is intended by *silica,* or *silex?*
26. In what is it contained, and in what is it soluble?
27. What is mentioned respecting the various uses of silex?

obtained, which has been called SILICON. It possesses no claim to be ranked with the metals, as it is without lustre, does not burn in oxygen gas, and is not a conductor of electricity.

Caroline. Then at present we must be content to know what silex assists to make, and leave to future discovery a knowledge of the articles of which it is itself composed(34).

Mrs B. ALUMINA, or ALUMINE, called also *argil* and *argillaceous* earth, is that substance which communicates the character by which the various kinds of clay are distinguished from the other earths. The name *alumine* is derived from alum, a salt of which it forms the base, and from which it may be readily separated in a pure state(35).

Alumine is contained in a great number of minerals, but is found chiefly in clay, mixed with silex, and usually coloured by the oxides of some of the metals. In its pure state it is soft to the touch, makes a paste with water, and hardens in the fire; which properties you perceive that it retains in its state of mixture. It is impervious to water, and from this circumstance is one of the most useful of the minerals. The beds of our lakes and rivers are formed of clay, and thus their waters, which would percolate through sand, and all other earthy materials, are retained. By its means, water is accumulated in the caverns of the earth, producing those reservoirs whence issue the springs, which spout out upon its surface(36).

Caroline. Then it is for this reason that clay was brought from a considerable distance to line the bottom and sides of the canal, where it passed through a sandy soil.

Mrs B. Yes, and this process is called *puddling*. Sometimes puddling is necessary for many miles together, and is essential to the value of the work, as without it the water would, in some places, sink away as fast as it could be let in.

From this retentive property, as regards water, clay is an important ingredient in sandy, loose soils; as it retains a sufficient portion of water to render them fertile(37).

Alumine is the basis of every kind of pottery, entering into the composition of brick, as well as that of the finest porcelain. The addition of silex hardens it, renders it susceptible of a degree of vitrification, and makes it perfectly fit for its various purposes. Indeed without this, the clay would contract so greatly in baking that the articles made would lose their form. The silex is said to give them body.

Caroline. I can scarcely conceive that bricks and china should be made of the same materials.

Mrs. B. Bricks consist almost entirely of baked clay; the clays used containing a large portion of coarse sand in a state of mixture. But to the clays used in the formation of earthen or stone ware, a portion of silex is usually added. For porcelain, or china, the Chinese use a mixture of two earths, called by them *petunsé*, and *kaolin*. Similar earths are found both in this country and in Europe, and very fine porcelain manufactured from it. The materials are essentially the same as for the coarse kind of ware, but they are in a more pure and a finer state. Porcelain owes its beautiful semi-transparency to the commencement of vitrification(38).

Emily. But the commonest earthenware, though not transparent, is covered with a kind of glazing.

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34. What is remarked respecting its decomposition?
35. What is *alumina*, and what are its other names?
36. What is said of its combinations and properties?
37. Clay is retentive of moisture; what is said respecting this?
38. What is remarked respecting pottery and porcelain?

Mrs B. That is as necessary to the use as to the beauty of the ware, as it would be liable to be spoiled and corroded by a variety of substances, if not covered with a coating of this kind. In porcelain it consists of a fine white glass, formed of such materials as are susceptible of vitrification. The glazing of common earthenware is made chiefly of oxide of lead, or sometimes merely of salt, which, when thinly spread over earthen vessels, will, at a certain heat, combine with a portion of the earthy material, and run into glass(39).

Caroline. And of what nature are the colours which are used for painting on porcelain?

Mrs B. They are all composed of metallic oxides; so that these colours, instead of receiving injury from the application of fire, are strengthened and developed by its action, which causes them to undergo different degrees of oxidation, according to their natures(40).

Alumine and silex are not only often combined by art, but they have in nature a very strong tendency to unite, and are found contained, in different proportions, in various gems and other minerals. Indeed, many of the precious stones, such as the ruby, oriental sapphire, and other oriental gems, consist chiefly of alumine(41).

Emily. Is alumine known to be a metallic oxide?

Mrs B. It has been proved, unequivocally, to be an oxide; and the ALUMINUM obtained from it exhibited some of the metallic characteristics. It was in the form of a grayish powder, difficult of fusion; but in oxygen gas it burnt very brilliantly, and produced alumine(42).

Emily. The other four earths you spoke of as being very rarely found, and I suppose therefore that but little is known of their properties.

Mrs B. ZIRCONIA has been discovered in a precious stone called *zircon* or *jargon*, from Ceylon: it has also been found in the hyacinth. GLUCINA is found in the beryl and the emerald; YTTRIA, in two or three minerals from Ytterby in Sweden, but not in any others. THORINA, in one mineral only, in Norway. The experiments performed upon them have furnished satisfactory indications that they are all of them oxides(43).

Caroline. There is a kind of stone which has excited much attention, and respecting which I should like to learn something. Whether it may be placed among the earths or not, I cannot tell, as it appears to belong to the heavens, or to some other world than this: I mean the stones which have, in so many instances, been known to fall from the atmosphere, or elsewhere.

Mrs B. These *meteorolites*, or *meteoric stones*, have completely puzzled the philosophers, and will probably continue to do so. Even the fact of their having fallen was disputed for ages, although attested most satisfactorily in the records of ancient and modern times. In most instances their fall has been preceded by a fiery meteor, and a loud explosion; immediately after which they have been seen to descend, some times singly, and at others in considerable numbers, and extending over a large space. When they have been examined soon after their fall, they have always been found hot. There is a remarkable similarity in their composition, in whatever quarter of the globe, and at whatever period of time, they may have fallen. Another curious circumstance distinguishes them, and that is they do not resemble

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39. How is the glazing of these articles effected?
40. What colours are used in painting on porcelain?
41. Mention some of the natural combinations of alumine.
42. What information have we concerning its composition?
43. What is observed respecting the remaining earths?

either of the known mineral substances on the face of the globe, although all the materials of which they consist are familiar to us(44).

Emily. And of what substances are they composed?

Mrs B. Their earthy matter consists of silex and magnesia, and they contain iron, in a native state, in the form of oxide, and in that of a sulphuret. This iron is always accompanied by another and a rare metal, called chrome, and generally with a considerable portion of a third, named nickel(45).

Caroline. I suppose that we might as well inquire of the poets as of the philosophers, how these stones are formed, and whence they come; as the philosopher, to obtain his answer, would have to invade the province of the poet, and mount into the airy regions of imagination.

Mrs B. Some have supposed that they are ejected from volcanos in the moon, with a force which brings them within the sphere of the earth's attraction. Others have imagined that the materials of which they are composed are volatilized by some mysterious process; that in their combination in the atmosphere they form the fiery meteors which precede their explosion; and that their heat originates in the condensation of their vaporized constituents. Fancy has also created little globes, revolving round our earth, within the sphere of its attraction, but too far off, and too small, to be visible. The collision or bursting of these terrellas, or little earths, has been thought to explain the phenomenon(46). Either of these opinions, when investigated, appears to be fraught with insurmountable difficulties, which I will not increase by any crude conjectures of my own upon a subject which has confounded the wisdom of the wise(47).

CONVERSATION XVIII.

ON THE METALS IN GENERAL.

Number of Metals known. Their distinguishing Characteristics. Ores and native Metals. Roasting, Smelting, and general process of Reduction. Oxidation and Reduction of the perfect Metals. Oxidation and Solution by Acids, with the formation of Salts. Nomenclature of Metallic Oxides. Alloys of Metals. Malleability and Ductility. Soldering. Welding. Combustibility of Metals. Gas holder. Hare's Oxy-hydrogen, or Compound Blowpipe. Combustion, Fusion, and Ignition produced by it. Modification of the Blowpipe, by condensing the Gases. Metallic Sulphurets formed with extrication of Light and Heat.

Mrs B. The METALS contained in the alkalies and earths, were all new to you, and beside these there are a number of others, which, though known to the chemist, are so sparingly diffused, or so rarely obtained, that you will most probably never see them. Those however to which our principal attention will be given, are familiar to you, being amongst the most useful as well as the most brilliant substances with which we are acquainted.

Caroline. To say the truth, I seem to be already so well acquainted with them, that, from further inquiry, I anticipate but little gratification compared

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44. State the nature and the history of *meteorolites.*
45. Of what materials are they found to consist?
46. What opinions have been entertained in regard to their origin?
47. What remark is made concerning these opinions?

with that which we have received from the contemplation of some of those mysterious and intangible beings, of whose properties, and indeed of whose very existence we were previously ignorant.

Mrs B. There is a great difference between familiarity with a countenance, and an intimate acquaintance with a character: we must close our eyes to avoid the former; to acquire the latter, we must exercise some of the noblest powers of our nature. You have already met with metals where you least expected to find them, and acquired a knowledge of properties in them of which you could have had no previous conception. The alkalies and the earths have presented us with a number of such bodies, and, believe me, you have yet much to learn respecting those with which you imagine yourself the most familiar. To treat of them fully would require more time than we can devote to the whole subject of chemistry, and we must therefore confine ourselves to a cursory view of their properties, whether examining them collectively or individually.

The whole number of metals known to the chemist amounts to about forty. Of these, seven only were known to the ancients, namely, *gold*, *silver*, *iron*, *copper*, *mercury*, *lead*, and *tin*. The others have all been discovered since the fifteenth century(1).

Emily. Is there any other property by which the metals are distinguished from other bodies, excepting that peculiar lustre which they exhibit when rubbed bright, and, if we are to judge by this alone, may we not sometimes be deceived?

Mrs B. Although the metallic lustre is the principal immediate characteristic of the metals, it is by no means the only one; their distinguishing features are the following:

They are all good conductors of caloric and of electricity. When their combinations with oxygen, sulphur, or similar substances, are submitted to the action of galvanism, the metals are always attracted by the negative pole of the battery; and for this reason they are denominated *electro-positive* bodies. They are in general good reflectors of light, which arises from that peculiar lustre which you have mentioned, and they are opake. Any substance possessing all these properties may be ranked as a metal(2).

Emily. You have not mentioned their great weight; are they not the heaviest bodies in nature?

Mrs B. Until the discovery of the bases of the alkalies, great specific gravity was ascribed to the metals, all those previously known being heavier than any non-metallic substance; but the lightness of these alkaline bases proves that this is not an essential characteristic of the metals(3).

A lustre resembling that of the metals is sometimes seen where we are convinced that it does not result from their presence. The brilliancy and colour of gold and silver are frequently exhibited on the wings of the moth, and on the body of the caterpillar, as well as on that of some other insects. There is also a class of mineral bodies called *pyrites*, which possess a lustre resembling that of the precious metals. These substances are metallic sulphurets; such as *sulphuret of iron*, or *iron pyrites*, *sulphuret of copper*, or *copper pyrites*, and *sulphuret of tin*, or *tin pyrites*(4).

Caroline. But it would seem, then, that these are not exceptions, as they are actually metallic substances.

Mrs B. By heating these sulphurets on a hot coal, a portion of the sulphur is sublimed, and a brown earthy mass alone remains; but although this

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1. What is said respecting the number and the discovery of the metals?
2. What are the distinguishing characteristics of the metals?
3. What remarks are made on the subject of their great specific gravity?
4. What articles possess a lustre resembling that of the metals?

mass contains the whole of the metal, it is without lustre. It is plain, therefore, that the metallic appearance is derived from the presence of the sulphur; or rather from the peculiar combination of the sulphur and the metal.

Caroline. The ores of many of the metals appear very beautiful in cabinets of minerals; in what state of combination do the metals usually exist in these ores?

Mrs B. In a great variety of states; but they are generally combined with oxygen, sulphur, earths, or acids, and there are frequently two or more different metals contained in the same ore. The ores are found near the surface of the earth in most parts of the world, but chiefly in mountainous districts, where the ground has been disturbed by earthquakes, volcanos, and other convulsions of nature. They are usually spread in strata or beds, called veins, and these veins are composed of a certain quantity of metal, combined with such articles as I have named, which are called *mineralizers*. Thus, speaking of a sulphuret of lead, we may say that the lead is *mineralized* by sulphur. The metals, sometimes, have no mineralizer, but are found in the pure metallic state, and are then called *native* metals(5).

Emily. These mineralizers are so different from each other, that the metals must necessarily be separated from them by very different methods. I have often heard of the roasting of ores, but do not understand what is meant by it, and whether it is always necessary, and with every kind of ore.

Mrs B. The process of extracting a metal from its ores is called REDUCTION. All that I can give you of the modes of procedure in this operation will be but a faint outline of its general principles(6). Ores are *roasted*, to separate sulphur, or other volatile articles from them. Roasting usually consists in placing the ore upon fires of wood, or coal, in the open air, and thus heating them to redness. But there are many ores, particularly the oxides, which do not require to be roasted(7).

The next operation is called *smelting*, that is melting out the metal from the ore. For this purpose it is put into a furnace with charcoal; the fuel and the ore being mixed together. The fire is then lighted and the whole mass intensely heated. The affinity between oxygen and carbon, when the latter is at a red heat, is such, that if the ore be an oxide, the carbon deprives it of its oxygen, and brings it into the metallic state(8).

Emily. You have shown us that iron and some other metals, when highly heated, combine with oxygen, and become oxides; I do not see, therefore, how, by the same operation, these same oxides should again lose their oxygen, and become metals.

Mrs B. The cases are very different. When iron, lead, and many other metals are heated in atmospheric air, they attract its oxygen, and become oxides. If they were perfectly surrounded by red-hot charcoal, this would protect them from oxidation, in consequence of its own superior affinity for oxygen; and in the process of smelting, the same superior affinity of the heated charcoal enables it to deprive the oxides of their oxygen, and thus to reduce them to the metallic state.

Caroline. Then the charcoal not only absorbs the oxygen of the air which feeds the fire, but that also which is contained in the oxides(9).

Mrs B. It does, and of course becomes converted into carbonic acid. Oxide of iron requires a heat too intense for us to attempt to reduce it; but we can easily operate upon the oxide of lead. Common red lead is an

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5. In what combinations and situations are the metals found?
6. What is meant by *reduction* as applied to a metal?
7. What is *roasting*, and for what purpose is it resorted to?
8. What is meant by *smelting*, and how is it effected?
9. In what way does charcoal operate in the process of reduction?

oxide of that metal, and were we to mix a portion of this oxide with pulverized charcoal, grease, or any substance containing much carbon, and heat them in the fire in a common tobacco-pipe, the lead would be reduced, and might be poured out in the metallic state(10).

Caroline. That we can very easily try, when we have a tobacco-pipe; I will get one presently.

Mrs B. We can try a similar experiment immediately, with one of these red wafers. Common red wafers consist of flour paste, coloured with red oxide of lead. We need therefore only set fire to the edge of one of these wafers, and hold it over a sheet of white paper, when the metallic lead will be seen to fall upon the paper in minute globules.

Emily. How curious, and yet how simple! the globules are numerous and quite distinct. The carbon contained in the flour has, in this case, produced the effect by combining with the oxygen of the red lead(11).

Caroline. But after the metals are reduced, and have run down from the ores to the bottom of the furnace, below the charcoal, I should suppose they would then again become oxidized.

Mrs B. The metal is then protected from the action of the air by allowing its surface to be covered with a melted mass of earthy or alkaline matter, which when so employed is called a *flux*, because it flows over the metal. Sometimes the earthy matter contained in the ores themselves fuses, and forms a glass which covers the metal. Potash, or other materials which produce the same effect, are frequently added, these additions being made according to the nature of the metal, or of the ore to be reduced. Rosin, tallow, or soap, will prevent the oxidation of lead, by keeping it from contact with the air, when melted in an open vessel over the fire(12).

Emily. Do all the metals when heated attract oxygen from the atmosphere, and become oxides? I have understood that they do not.

Mrs B. Some of the metals have but a feeble affinity for oxygen, and if combined with it, part from it very readily. The oxides of gold, silver, mercury, and platinum, may be reduced by heat alone, without the addition of any coaly matter. Their oxygen unites to the caloric, assumes the gaseous form, and leaves the metal in a pure state(13).

Caroline. The very means therefore by which some metals are oxidized, will separate the oxygen from those you have just named, and reduce them to the state of pure metals. But how can they be made into oxides at all, if heating them in contact with air will not effect it?

Mrs B. Those which cannot be oxidized by heat alone, were formerly called the *perfect metals*, a name now nearly out of use. They may be oxidized by sending through them powerful electric discharges; but for this purpose they must be reduced to the form of fine wire, or of thin leaves, and the oxide is obtained in but small quantities. All metals however yield to the oxidating power of some one or more of the acids. You, I am sure, will recollect what you were formerly told upon that subject(14).

Caroline. I believe I do. I think you informed us that the acids and the metals unite together and form salts; or rather that the acids unite to the oxides of the metals and form them, as, in all cases, the metal must be oxidized before it can combine with the acid(15).

Mrs B. Yes; and, of course, if a metal be put into an acid, and then

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10. How may this be shown by means of red lead?
11. How may a wafer be made to answer this end?
12. What are *fluxes*, and for what purpose are they employed?
13. What is observed respecting gold, silver, mercury, and platinum?
14. What were such metals called, and how may they be oxidized?
15. What is said of the oxidation of metals by acids?

undergo solution, a double process must be carried on. In order to its conversion into a metallic salt, the metal must first be oxidized, and the oxide then dissolved by the acid. In making hydrogen by the action of dilute sulphuric acid upon iron, the metal, you know, obtained the oxygen from the water, and its hydrogen was consequently liberated; but it more frequently happens in the solution of a metal by an acid, that the metal obtains its oxygen by decomposing a portion of the acid, the oxide thus formed being dissolved by the remaining acid(16).

Emily. Then, in this case, you do not obtain any hydrogen gas?

Mrs B. Certainly not; whatever gas escapes must be that which results from the decomposition of the acid, and must depend therefore upon the composition of that acid (17).

In this phial there is *nitric acid*, some of which I am about to pour over the shreds of copper in this glass, when a violent effervescence will take place, and a large quantity of gas will be extricated.

Caroline. Oh, what a disagreeable smell, and what a deep orange coloured vapour escapes! pray what is that?

Mrs B. It is, like the acid itself, a compound of nitrogen and oxygen, but containing less oxygen. Its particular composition I shall hereafter explain; you can, however, form some judgment about it when I tell you that it is *nitrous acid*(18).

Emily. The effervescence is now over. I suppose, therefore, that the metal is both oxidated and dissolved.

Mrs B. Yes. And were we to evaporate the fluid, we should obtain the salt called *nitrate of copper*, in the solid state; as you see it in this phial(19).

Caroline. Pray, what would have been the consequence, Mrs B., if instead of metallic copper you had put an oxide of copper into the nitric acid? I do not see in this case how any decomposition of the acid could have been effected.

Mrs. B. Your inference is correct: had we put in an oxide of copper, the metal being already oxidized, no effervescence would have taken place. Nor would there have been any decomposition of the acid; but the oxide would have been quickly dissolved, and the same kind of salt produced as in the first solution(20).

Emily. It seems rather strange that the metal when put into dilute acids, should sometimes decompose them, and at others decompose the water.

Caroline. I think I can trace the reason of this. When the oxygen in the acid is united to its base by an affinity less powerful than that of oxygen for hydrogen, the acid is decomposed; and when the reverse is the fact, water is decomposed(21).

Mrs B. Your explanation is very good. There are some of the acids which have a strong affinity for the oxides of some of the metals; yet, when concentrated, that is, deprived as far as possible of water, they will not act upon the pure metals. This is the case with sulphuric acid and iron: if the acid be deprived of all the water with which it will part, it will not act upon iron, because its oxygen is united to its sulphur by an affinity too powerful for the iron to overcome(22).

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16. What double action is necessary to their conversion into salts?
17. What circumstance will determine the kind of gas given out?
18. Detail what is said respecting nitric acid and copper.
19. What is the salt produced, and how is it obtained?
20. What would result from putting oxide of copper into nitric acid?
21. What determines whether the acid or the water shall be decomposed?
22. What is said respecting concentrated acids and metals?

Emily. You have taught us that many of the metals are capable of uniting to different proportions of oxygen, and that, from this cause, the oxides differ very much in their character. If all these different oxides are dissolved by the acids, there must be as many different salts of each metal as there are oxides(23).

Mrs B. Your remarks remind me of what I had intended to inform you respecting these different oxides. Do you recollect the names by which we distinguish the several oxides of the same metal from each other?

Emily. I will endeavour to repeat them as I have frequently done to myself, in order that I might not forget them.

When a metal unites to oxygen in one proportion, it is simply called an oxide. When in two, the first is called the *protoxide*, and the second the *deutoxide*, or *peroxide*. When in three, we have the *protoxide*, *deutoxide*, and *tritoxide*, or *peroxide*; and sometimes there is a fourth called the *quadroxide*. The name *peroxide* is usually given to the last of the series, whatever may be its number(24).

Mrs B. Very good. In the greater number of instances, acids unite with the protoxide only, those which are more highly oxygenated being altogether insoluble(25). Do you remember in what way we obtained oxygen gas by the action of sulphuric acid?

Caroline. You mixed it in a retort with a metallic oxide which you called the black oxide of manganese, and then heated the mixture over a lamp, when the oxygen escaped. I have frequently puzzled myself to find out the source of the oxygen in this instance.

Mrs B. I think you will be able to discover it when I inform you that the black oxide of manganese is the *tritoxide* of that metal, and that when it is mixed with the sulphuric acid, and heat applied, a sulphate of manganese is formed, consisting of the acid combined with the *protoxide*(26).

Caroline. Oh, yes, now I see the operation plainly. The acid combined with the protoxide and the excess of oxygen contained in the tritoxide was disengaged, and escaped in the gaseous form.

Mrs B. When, without the presence of an acid, this black oxide is heated to redness, a similar change takes place. Oxygen gas escapes from it, and, instead of a tritoxide, it becomes a deutoxide(27).

But we must hasten to some other general properties and combinations of the metals. Do you know what is meant by an *alloy*?

Emily. I understand by an alloy something which debases a metal, and renders it less valuable.

Mrs B. Your idea is not quite correct. Alloys are merely combinations of two or more metals with each other. Gold and silver are alloyed with copper, when they are to be made into coin, or into articles of plate or jewelry. Standard gold and silver contain about one-twelfth part of alloy, and they are rendered harder, and more fit for use by this mixture. Brass is an alloy of copper and zinc; bell-metal, an alloy of copper and tin; and pewter, of tin, with lead, antimony, or some other metal or metals; its composition being various(28).

Emily. I am a little at a loss about the nature of tin. Our tin dishes, and cups, and kettles, differ very much from a pair of tea-pots which we have in use, and which are warranted to be pure tin.

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23. What remark does Emily make on the solution of oxides?
24. Describe the manner of naming the metallic oxides.
25. Which oxide of a metal does an acid generally dissolve?
26. How is this shown by the black oxide of manganese?
27. How do acids, or heat, extricate a portion of its oxygen?
28. What are *alloys*, and what particular examples are given?

Mrs B. What we call tin, or tin plates, and out of which the common tin ware is made, is thin sheet iron covered with tin, just as the inside of copper saucepans is covered in the operation called tinning. This coating of tin is applied by dipping the sheets of iron, properly prepared, into melted tin. An alloy of tin and iron is thus formed upon the surface, to which a thin coat of pure tin adheres, whilst the middle is sheet iron.

Caroline. That accounts for the rusting; (I beg your pardon, now that I am a chemist, I should say oxidizing) of the vessels when they have been much used; the tin in this case being worn off from the surface of the iron.

Mrs B. Pure tin is a very soft malleable metal, which, if made thin, like tin ware, would bend as easily as paper(29).

Emily. By malleable, I believe you mean soft and flexible, do you not?

Mrs B. Not precisely. Some metals are said to be *malleable* and *ductile*, and others to be brittle. Malleability and ductility, though both opposed to brittleness, are yet different from each other. *By malleability is meant the capacity of being beaten out into very thin plates or leaves; and by ductility, a capability of being drawn into very fine wire*(30).

Caroline. But certainly those metals which can be beaten into thin leaves may also be drawn into fine wire: I do not, therefore, see the distinction between the two.

Mrs B. Nevertheless, these properties, although always combined to a certain degree, are absolutely and evidently distinct. Iron, for instance, can be drawn into wire of extreme fineness, yet it cannot be beaten into very thin leaves; and other examples, equally decisive, might be given(31).

Caroline. That is strange, and I cannot conceive of any principle upon which we can account for such a fact.

Mrs B. I can only tell you what plausible conjecture has been made upon this point, which, if admitted to be true, will satisfactorily account for it. It has been supposed that the minute particles of the most *ductile* metals are in the form of fine fibres like cotton, whilst those of the *malleable* metals are in the form of flat plates like spangles(32). The former structure would evidently be best adapted to the formation of wire; the latter to extension into thin leaves. Remember, however, that this explanation is to be taken as conjecture only, although it derives some support from the known fibrous texture of iron, the most ductile of all the metals. We must now return, from our digression, to the subject of alloys, respecting which I have something further to say.

Emily. I was about to inquire concerning them; whether we are to consider them as mere mechanical mixtures, or as chemical combinations of the metals?

Mrs B. They are, undoubtedly, chemical compounds; for, although they retain their general characteristics as metals, they undergo changes which are evidently not mechanical. In many instances the alloy has neither the colour, specific gravity, tenacity, or fusibility, which would have been anticipated from a knowledge of the separate metals. Copper, which is red, united to zinc, which is white, produces brass, which is yellow. Copper and tin, which are both malleable, form bell-metal, which is extremely brittle. A compound of five parts of *bismuth*, three of *tin*, and two of *lead*, is called the fusible alloy, and melts at the heat of boiling

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29. What observations are made respecting tin?
30. What is meant by *malleability* and by *ductility*?
31. What proof is given of a difference in these properties?
32. Upon what circumstance is this supposed to depend?

water, although the most fusible of these three metals, when alone, requires a temperature of between four and five hundred degrees to melt it. Were the alloys mere mixtures of the metals composing them, they ought, when fused, to separate in consequence of the difference of their specific gravities(33).

Emily. When articles of metal are broken, I hear sometimes of their being *soldered*, and at other times of their being *welded*. What is the difference between these processes?

Mrs B. *Soldering* is the uniting of two pieces of metal together by another metal (generally itself an alloy), which is melted upon, and runs in between the parts to be joined. The *solder* must, of course, be more fusible than the metal to be soldered(34). Two pieces of iron may be soldered, or *brazed*, as it is called, by means of brass. Silver or brass may be soldered by a mixture of brass and silver, called *silver solder*, which fuses much more readily than either of them alone. Lead, or tin, is soldered by a mixture of these two metals themselves, which, as in the case of silver solder, melts at a temperature below that of either of its constituents. This latter mixture is called *soft solder*, whilst the former kinds are denominated hard solders(35). When either of these solders is applied, the metal is made clean and bright, and with the solder some substance is used which operates like the fluxes employed in fusing the metals; that is, they keep off the atmospheric air, and thus prevent oxidation, which would defeat the process(36).

Caroline. I think that I understand the nature of *welding*, as I have several times seen it performed. The two pieces of metal to be joined are heated very highly, then placed upon each other and struck with a hammer, which unites them perfectly. When I have seen this done it has, however, always been with iron.

Mrs B. Your description is very good, and the reason why you have seen no other metal than iron welded, is because it is the only one that can be so united, excepting platina, which does not often pass under the hammer of the common smith(37).

The last general property of the metals which I shall notice is their combustibility, which I have the means of exhibiting to you very brilliantly. This will close our present conversation, and at our next meeting we shall examine some of the individual metals.

Emily. We have been anxiously waiting to see the operations performed by the OXY-HYDROGEN OR COMPOUND BLOWPIPE. We have heard the experiments with it described in such glowing colours, its power of combustion and fusion so highly extolled, and the light which is emitted in these processes represented as so dazzling, that I think the reality must disappoint the anticipation.

Mrs B. You need not apprehend disappointment in witnessing the effects of this instrument, although we must limit ourselves to a very few examples of its power. Lavoisier had applied oxygen gas in a similar way, but the apparatus before you is not only more powerful, but much more manageable than that used by him. When oxygen is employed alone, as was the case in the experiments of the French chemist, the article to be operated upon must be first ignited, and then placed under the stream of oxygen; whilst, in the compound blowpipe, the burning hydrogen renders all this unnecessary.

Caroline. Is there any thing peculiar in the construction of the tin ves-

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33. What proves that alloys are chemical combinations?
34. What is meant by *soldering*, and how is it effected?
35. What particular exemplifications are given?
36. What precaution is necessary to prevent oxidation?
37. What is *welding*, and what metals may be welded?

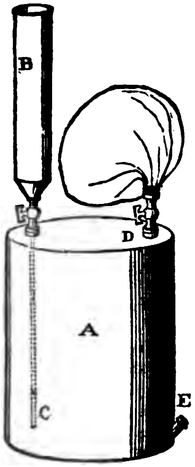
sels in which you have the gases collected? You have several times used, but never particularly described them.

Mrs B. These vessels which are called air, or gas, holders, are very convenient for collecting the gases in large quantities, and are much employed by the chemist.

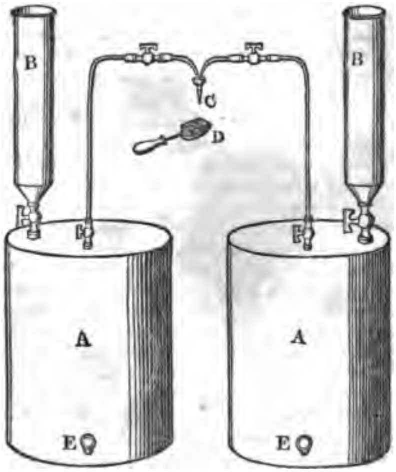
This (fig. 1.) is an air-holder, made, as you observe, of tin, and japanned to keep it from rusting. Its construction is very simple. It has three openings; one for filling it with water, another for admitting the gas which is to displace the water, and the third to allow the gas to escape when wanted. It is first filled with water through the funnel attached to the top, the spout or opening near the bottom being stopped with a cork. The second opening in the top is for the escape of the gas, and this may be opened or closed as required(38).

Emily. Was this the kind of instrument employed by Lavoisier?

Air Holder.
Fig. 1.



Hare's Oxy-hydrogen Blowpipe.
Fig. 2.



[Fig. 1. A, Body of the gas-holder. B, a funnel for filling it with water. C, a tube which extends from it nearly down to the bottom of the vessel, its end always dipping under water. D, a turn cock to allow of the escape of the gas when wanted. E, a tube opening into the body of the vessel, to admit a tube, or retort, for filling it with gas, and for allowing the water to escape as the gas ascends.

When filled with gas, and water is poured into the funnel B, its pressure will force the gas through the opening at D, to which a blowpipe, bladder, or other instrument, may be attached.

Fig. 2. Consists of two air holders constructed exactly like the foregoing. One of these is to be filled with oxygen, the other with hydrogen. Two tubes, one connected with each, have a common opening at C. In these tubes there are turn cocks to regulate the discharge of the two gases. At D is the substance to be acted upon, which may be placed upon a piece of charcoal, or any suitable support.]

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38. Describe the vessel usually called a gas-holder?

Mrs B. Yes; and the *compound blowpipe* which I use is composed of two such air-holders, one filled with oxygen, the other with hydrogen. There is a pipe leading from each of these which terminates in a single opening, from which the gases may issue either separately or unitedly, and in such proportions as may be desired.

The metal to be burnt is most commonly placed upon charcoal; it is held under the jet, or opening, when a stream of hydrogen is allowed to escape, which stream is then ignited. The metal exposed to the flame will soon become red-hot, and when this has taken place oxygen is made to flow upon it, from the other receiver. This will produce a heat of very great intensity, and a piece of cast iron exposed to it will, as you see, burn very rapidly(39).

Caroline. What a volume of splendid sparks! You seemed during the combustion to be enveloped in fire. How much more brilliant this is than the burning of the wire in the jar of oxygen!

Emily. Did you observe that the iron actually boiled up, like heated water. This experiment could not indeed disappoint the expectations of any one(40).

Mrs B. A piece of steel watch spring will burn in much the same manner. Copper you perceive burns with a beautiful green flame, and the other metals with flames differently coloured, and with different degrees of brilliancy, whilst they fly off in the state of oxides(41).

Emily. Those which have been called perfect metals, such as gold, silver, and platina, as they are not oxidized by heat and air, will not burn, I suppose, but merely become ignited and fused.

Mrs B. Such is the intensity of the heat, that every metal yields to its influence. Platina will not melt in any of those furnaces in which other metals are fused; but under the action of the compound blowpipe it is not fused merely, but rapidly dissipated in vapour. Gold and silver likewise burn, being not only oxidized, but actually vaporized(42).

Articles which had resisted every previous attempt to fuse them, such as the pure earths, have been subdued by this instrument. Incombustible substances cannot, of course, be burnt by it, yet the light which they emit is so extremely dazzling, that the eye can scarcely bear it. A tobacco-pipe stem, or a piece of lime, answers well for this experiment. The compound blowpipe has not served the purpose of showing brilliant experiments merely, but has greatly aided the chemist in his researches(43).

Caroline. To whom are we indebted for this elegant and efficient mode of obtaining the command of so high a degree of temperature?

Mrs B. To Dr Robert Hare of Philadelphia, now professor of chemistry in the university of that city, who published an account of it in the year 1802. The effects produced by it upon various substances were subsequently more fully ascertained by himself, and by Professor Silliman of Yale college, and made known in the journals both of this country and of Europe(44). It is much to be regretted that attempts were made, many years afterwards, by an English chemist, to deprive Dr Hare of the honour of the invention, and of the investigations to which it gave rise.

Caroline. And were the experiments in England performed with an instrument exactly like that which you have employed?

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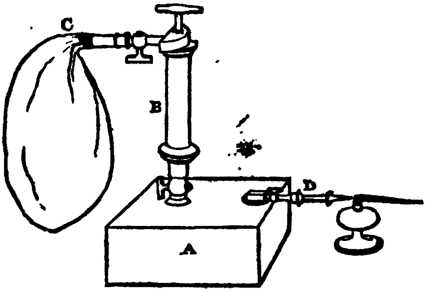
39. Describe the compound blowpipe and the mode of using it.
40. How is cast iron affected when exposed to its action?
41. What is observed respecting some other metals?
42. How are gold, silver, and platina acted upon?
43. What is said of the fusion and ignition of different substances?
44. Who was the inventor of the compound blowpipe, and what observations are made respecting it?

Mrs B. That used by me is not precisely in the form of those employed by Dr Hare, but the principle of its action is the same. In the English instrument, the two gases were mixed together in the proportions in which they combine to form water, and forced by a condensing syringe into a strong copper box or reservoir, whence they issued by their elasticity when a vent was opened for that purpose. This is the instrument, but it is not charged with the gases(45).

Blowpipe with condensed Oxygen and Hydrogen Gases.



[A, the reservoir for the condensed gases. B, the condensing syringe. C, the bladder for supplying oxygen and hydrogen. D, the moveable jet.]

Emily. But such a mixture of the gases is extremely explosive; how is it, then, that when ignited, the apparatus is not blown to pieces?

Mrs B. This has actually and repeatedly happened, to the imminent danger of the operator. When the gases are highly condensed, and the aperture very small, they flow out so rapidly as to prevent the flame from passing inwards, but the danger is every moment increasing, and several contrivances have been made to obviate it; but though lessened, it still exists to a very considerable extent(46).

Emily. The instrument with condensed air is certainly the most compact of the two, but if this is considered as a point of importance, why cannot the two gases be separately condensed in different vessels?

Mrs B. This has been proposed, and might very readily be effected; but those who have been in the habit of using the instrument as employed by Dr Hare, are satisfied that the effects it is capable of producing, are, in all respects, equal to those obtained by the condensation of the gases, whilst it is entirely free from the danger of explosion.

Caroline. You appear, Mrs B., to be making a mixture of the filings of copper and of sulphur: are these to be submitted to the action of the blowpipe?

Mrs B. No; but before closing our present conversation, I am about to show you a kind of combustion which takes place without the presence of oxygen, or of either of those agents which have been denominated supporters of combustion. Most of the metals, you are aware, will combine with sulphur, and become converted into sulphurets. To produce this combination, it is in general sufficient to expose the sulphur and the metal, in mixture, to a degree of heat not far surpassing that which is required to fuse the former substance.

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45. What modification of this instrument has been since made?
46. What objection exists to the blowpipe in this form?

The temperature necessary to produce this result does not exceed that of three hundred degrees. When this has been attained by the mixture, the heat will suddenly rise to that of ignition, and the whole mass will assume a glowing red appearance(47).

I put this mixture of flowers of sulphur and copper filings into a common Florence flask, which I close to prevent the admission of air. I now place the flask over a lamp and heat it slowly, and you will presently see that ignition will take place, with all those appearances which we indicate by the word burning(48). The disengagement of heat, in this case, results merely from the union effected between two combustibles, no other substance being present. The compound formed is still capable of undergoing combustion by the agency of oxygen gas, which would convert its sulphur into an acid, and its metal into an oxide.

Emily. And it seems closely to justify the remarks formerly made upon the subject of combustion, and to prove that it may result from intense chemical action, without those aids by which it is ordinarily supported(49).

CONVERSATION XIX.

ON THE PARTICULAR METALS.

Metals known to the Ancients. Those which have been discovered since the 15th century. Gold, its mines, modes of gilding with, and its general properties. Platinum, its properties, and the ignition of Spongy Platinum by Hydrogen. Metals contained in the ore of Platinum. Silver, Nitrate, and Fulminate of Silver, and other Fulminates. Cinnabar, Mercury, its Uses and Properties. Iron, Cast Iron, Steel, and Plumbago. Magnetic Property of Iron and other Metals. Copper, its Uses and Combinations. Lead, its Oxides, and other Combinations. Tin, its Alloys and properties. Zinc, and its combinations. Acidifiable Metals. Arsenic, Chrome, and Antimony; their properties and uses. Medicines and Pigments obtained from Metals.

Mrs B. I have already intimated to you that in examining the metals individually, I should call your attention only to the most important of their particular properties. To do more than this would not be found either useful or agreeable, and to do less would be to neglect some interesting facts respecting a class of bodies which occupies a very conspicuous station, whether viewed in its connexion with science or with the arts of civilized life.

Caroline. I have felt a much higher degree of interest in the metals than I had thought it possible for them to excite, and am therefore prepared to continue the subject with an assurance of undiminished satisfaction.

Mrs B. I have prepared a catalogue of the known metals, and wish you each to take a copy of it. I have not included those metals which are the bases of the alkalies and of the earths, as they have been separately considered. This list is made out chronologically, containing the date of the discovery of all the various metals, excepting the seven which were known at a period antecedent to that of authentic history.

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47. In what way may some of the metals be converted into sulphurets?
48. How may the light and heat given out be experimentally shown?
49. What fact is this experiment calculated to exemplify?

Names of the metals.	*Date of their discovery.*	*Names of the metals.*	*Date of their discovery.*	*Names of the metals.*	*Date of their discovery.*
Gold	Known to the Ancients. (1)	Arsenic	1733	Titanium	1791
Silver		Cobalt	1733	Chromium	1797(2)
Iron		Platinum	1741	Columbium	1802
Copper		Nickel	1751	Palladium	1803
Mercury		Manganese	1774	Rhodium	1803
Lead		Tungsten	1781	Iridium	1803
Tin		Tellurium	1782	Osmium	1803
Antimony	15th century	Molybdenum	1782	Cerium	1804
Zinc	1520	Uranium	1789	Cadmium	1818(3)
Bismuth	16th century				

Emily. There is one thing very remarkable in this list, and which serves to exemplify the rapid progress of chemistry within a few years. I allude to the modern date of the discovery of so many of the metals(4).

Mrs B. And if we had included those which are furnished by the decomposition of the alkalies and the earths, this fact would have been rendered still more striking, the whole of them having been recently made known. I have not thought it best to give you a systematic classification of them according to any relationship which they bear to each other in their properties. While examining them we shall proceed in such order as may appear to be most convenient, beginning with *Gold.*

Gold is the only simple metal which has a yellow colour. It is always found in the metallic state; sometimes nearly pure, at others considerably alloyed with silver or with copper. Although nature has diffused it in every country, it has been either in quantities so sparing, or in situations whence it is procured with such great labour, as to make it the most costly of those metals which have been brought into general use. In some places it is obtained by washing the sand of rivers, and in others from soils in which it is contained in minute particles. Occasionally it is found in veins in solid rocks, whence it is necessary to quarry immense portions of stone, in order to obtain the produce of a thin stratum of gold. Shafts are sometimes sunk, in the manner of wells, to the depth of many hundred feet, down which the miners descend by means of ropes, and labour in great peril from falling stones, accumulated water, foul air, and other causes. Mines of gold are wrought in every quarter of the world, but Mexico, and some of the countries of South America, have furnished more of this metal than all the other regions of the globe collectively(5).

Caroline. North Carolina has lately been much spoken of on account of its gold mines. I have seen several specimens said to have been brought from thence.

Mrs B. A very considerable quantity has been found there. It is diffused over an extensive region, not only in that state, but extending into Virginia, South Carolina, and Georgia. This region resembles that of the gold districts of Mexico. Some years ago there was a piece of gold found in North Carolina, which weighed twenty-eight pounds. This large mass I saw de-

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1. What are the seven metals which were known to the ancients?
2. What others were discovered previously to the year 1800?
3. Name those discovered during the present century.
4. What particular fact does the table of the metals exemplify?
5. In what conditions and in what countries is *gold* found?

posited in the United States mint in Philadelphia. Other pieces have since been found weighing several pounds, but this is an event of very rare occurrence(6).

Caroline. I believe that gold is beaten into leaves which are much thinner than those of any other metal.

Mrs B. It is; and such is its malleability, that about 280,000 leaves of gold piled upon each other, will measure but one inch in thickness, and the gilding upon silver wire is but about a twelfth part of the thickness of one of those leaves; yet the silver will be found completely covered and hidden by the gold, even when the wire is examined by a microscope(7).

Emily. A perfect coating formed by a layer not the three millionth part of an inch in thickness! How extremely minute must be the particles of gold!

Mrs B. Gold may be dissolved in a mixed acid, which has been called *aqua regia.* It is made by mixing together portions of *nitric* and *muriatic* acids. Neither of these alone will dissolve the metal, but they do so very readily when combined. I put a leaf of gold into each of these wine glasses; upon one I pour nitric, upon the other muriatic acid, and you see that in both, the leaf remains unchanged. I now pour the two together, and the gold is immediately dissolved. This mixture of acids is now usually denominated *nitro-muriatic acid*, and the salt of gold which results from this combination, *nitro-muriate of gold*(8).

Caroline. The muriatic acid, I recollect, is that which, with ammonia, forms *sal ammoniac*, or the *muriate of ammonia.*

Mrs B. Gold, from its beauty and durability, is employed for gilding the less valuable metals, as well as numerous articles made of wood, and other materials. Gilding is effected in various ways. Sometimes the metal, in thin leaves, is made to adhere by means of size, or varnish; at others the gold is dissolved in mercury, and in this combined state is applied to silver, copper, bronze, or other metals to be gilt(9).

Caroline. By saying that the gold is dissolved in mercury, you mean, I suppose, that an alloy of these two metals is prepared by melting them together.

Mrs B. Mercury, being already in the fluid state, will, like other fluids, dissolve those solids to which it has a strong attraction. Gold is one of them, and although the solvent power of the mercury is increased by heat, it will operate whilst cold. Silver, copper, and in fact most of the metals, combine in like manner with quicksilver. Compounds of this kind are usually of a soft, pasty consistence, and, although of the nature of alloys, they are classed by themselves and called *amalgams.* Thus we say an *amalgam of gold*, an *amalgam of tin*, &c.(10).

When the amalgam of gold is used for gilding, it is spread over the surface of the metal to be gilt, which must therefore be of a kind to which it has an affinity. The metal so covered is then heated over a charcoal fire, which volatilizes the mercury, whilst the gold is left adhering to the surface intended to be gilt. This operation is sometimes called, though not very appropriately, water gilding(11).

We must now leave the consideration of gold, and proceed to that of a less costly metal.

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6. What is remarked respecting gold mines in the United States?
7. How thin may gold be beaten, or be spread in gilding?
8. In what acid can gold be dissolved?
9. By what methods may gold be applied in gilding?
10. To what combination of metals is the term *amalgam* applied?
11. How is the amalgam of gold employed in gilding?

Emily. Let me first try if I can repeat the principal properties of gold. It is never mineralized, being always found in the metallic state. It may be oxidized by electricity, or by aqua regia, but not by heat, moisture or air, either individually, or united; and it is one of those metals, the oxides of which may be reduced by heat alone. It is more malleable than any other metal, is the only one of a yellow colour, brass being an alloy; and with mercury it forms an amalgam(12). Am I correct, Mrs B.?

Mrs B. Perfectly so; and we will now examine the metal to which I just now alluded; it is PLATINA or PLATINUM.

Caroline. I observe that you frequently give the names of the new metals with a termination in *um.* I think science would do better without these double names.

Mrs B. Uniformity has been attempted in this as well as in most of the other departments of chemistry. Most chemists have adopted the termination in *um*, in naming the new metals. No one, however, expects the long established names of gold, silver, iron and copper, to be changed in conformity with new rules; nor shall I always follow them in our conversations, even with the new metals(13).

Pure *platinum* is of a white colour, somewhat resembling silver. Like gold, it is always found in the metallic state, and usually associated with that metal. Formerly it was obtained only from the mines of South America, but latterly it has been discovered in considerable quantities in the Uralian Mountains, and the Russians have actually introduced a coinage of this metal(14). It is the heaviest body known, its specific gravity being greater than that of gold; and it is so infusible as to retain the solid state in furnaces the most intensely heated. It may be melted, however, by the oxy-hydrogen blow-pipe, in the current of a powerful voltaic battery, and by the heat of the solar ray contracted by a lens(15).

Caroline. If platina cannot be fused in a furnace, how then can it be brought into large masses for use in the arts?

Mrs B. By the property of welding, possessed only by it and by iron. Platina is soluble in the same acid which dissolves gold, but in no other; and on account of the little effect produced upon it by heat and most of the chemical agents, it is found of great use in forming some of the vessels required in the laboratory(16).

Emily. What is the use of that neat little instrument which you have taken from the case? Can it have any connexion with platinum?

Mrs B. It is intended to exemplify a very remarkable property in this metal. A soft, spongy mass of platinum may be obtained by dissolving it in *nitro-muriatic* acid, precipitating it from its solution by means of muriate of ammonia, and then igniting the precipitate in a crucible. It is now called *spongy platinum.* If a stream of hydrogen gas, at the common temperature, be made to blow upon this spongy mass, or even upon platinum made into thin leaves, or very fine wire, and rolled up so as to form a ball about the size of a pea, the metal will become ignited, and will set fire to the gas. This little air-holder contains hydrogen, which is forced out by the pressure of water, as in the larger instruments. When I turn the key, the gas from the jet blowing upon the little ball of platina, quickly

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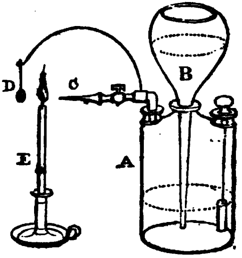
12. Give a recapitulation of the general properties of gold.
13. What is said of the termination in *um* in naming the metals?
14. What is the appearance of *platinum*, and where is it found?
15. What is said respecting its infusibility?
16. How are separate pieces united together, and what acid dissolves it?

ignites it. This, in its turn, sets fire to the gas, the flame of which lights the taper over which it passes(17).

Spongy Platinum Apparatus.



[A. Glass vessel containing diluted sulphuric acid, and within which is suspended a cylinder of zinc, upon which the acid acts and generates hydrogen. This gas forces the liquid up the tube, and into the upper vessel B. When the jet C is opened, the hydrogen will pass out, and coming into contact with the ball of spongy platinum, D, will ignite it. The gas will then inflame, and light the taper E.]

Caroline. Wonderful indeed! and I should think it a phenomenon very difficult to account for. The metal must remain unchanged, as hydrogen cannot produce any chemical effect upon it.

Mrs B. The chemists do not pretend fully to explain it. There appears, however, to be a very strong analogy between this phenomenon and the mechanical absorption of the gases by charcoal (p. 154). The presence of the oxygen of the atmosphere is necessary to the success of the experiment; and it seems as though the hydrogen was mechanically condensed by the spongy platinum, and thereby enabled to combine chemically with the oxygen, and thus to produce heat and light(18).

In these metallic grains, which are called the ore of platinum, four metals have been discovered, and named PALLADIUM, RHODIUM, OSMIUM, and IRIDIUM.

They have been found in but small quantities, and you must at present be satisfied with the knowledge of their existence only. If you wish to inquire further concerning them, any modern treatise on chemistry will enable you to satisfy your curiosity(19).

Emily. I never should have supposed that the grains of platina in this phial consisted of so many different metals: this ore seems indeed to be an alloy of alloys.

Mrs B. Besides platinum and the four metals just named, some of the older metals, also, are contained in these grains, making the whole number amount, it is said, to ten or eleven.

We will now pass on to the metal which is generally esteemed next in beauty to gold; that is *Silver*.

SILVER is most commonly found in the metallic state alloyed with other metals, but it is also mineralized with sulphur, forming a sulphuret of silver. In malleability, silver is inferior to gold only; it is also more susceptible of being oxidized. When kept intensely heated for a considerable length of time, in contact with oxygen, it absorbs a portion of it. Its oxide, however, may be reduced by heat alone(20).

Caroline. I have understood that the substance called *lunar caustic*, which is used in surgery, is a preparation of silver. If so, my own experience has taught me that silver is not always productive of pleasure.

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17. What is spongy platinum, and how is it employed to produce ignition?
18. On what principle is this supposed to be effected?
19. Name the metals discovered in the ore of platinum.
20. What are the first observations made respecting *silver?*

Mrs B. Both the *lunar caustic* and the *permanent marking ink* are *nitrates of silver;* the former in a solid state, the latter in solution. Nitric acid very readily dissolves silver, and this nitrate, dried, fused, and cast into moulds, forms lunar caustic, which rapidly corrodes the flesh. When the nitrate of silver is used as a marking ink, the linen is first moistened with a solution of carbonate of soda or some other alkali, then dried, and the writing executed with the nitrate of silver, which stains the linen of a permanent dark colour(21).

Emily. I have heard it said that those dangerous playthings called torpedoes, which explode when thrown upon the floor, derive this property from some preparation of silver. Is this the fact?

Mrs B. There are several metallic preparations which are extremely explosive; particularly those of gold, mercury and silver. That used in the kind of crackers to which you allude, is called *detonating silver;* but there is a similar compound called *fulminating silver*, which is incomparably more violent than the former. It is considered unsafe to prepare more than a single grain of it at once. After it is made, it is dangerous even to remove the vessel in which it is contained, as the slightest agitation will cause it to explode. Even a drop of water being allowed to fall on it will produce the effect.

Emily. And do these different preparations appear to owe their explosive property to one common cause?

Mrs B. They do. There is a peculiar acid called *fulminic acid*, which is formed under particular circumstances when such metals are present, and which combines with them, producing salts denominated *fulminates.* This acid is a compound of carbon, nitrogen, and oxygen, which are separated from very slight causes, and suddenly assume the gaseous form(22).

MERCURY OR QUICKSILVER.

You need not to be informed what article is to be our next subject of inquiry, although the phial containing it is without a label.

Caroline. No; *quicksilver* can never be mistaken for any other metal: its great weight, and its fluidity in the coldest weather, are too characteristic to allow of our calling it by a wrong name. It is so peculiar a substance that every one seems to find amusement in playing with it. Is it found in this state in the mines, or is it a solid mineral?

Mrs B. Sometimes, though rarely, it is found fluid, and is then called *virgin quicksilver.* Its ore is usually a sulphuret. The colour called *cinnabar* is a *sulphuret of mercury.* The beautiful red paint, *vermilion*, is also compounded of the same materials, prepared with great care by the manufacturing chemist(23).

Mercury is much used at the gold mines, as it amalgamates readily with gold, and collects from the soil those fine particles which could not be obtained in any other way. In many silver mines, also, the metal is wholly collected by amalgamating it with mercury(24).

Emily. In what way is the quicksilver fixed upon the backs of looking glasses? It seems remarkable, that although it is a fluid, it does not run off.

Mrs B. The silvering of looking glasses is effected by an amalgam of

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21. For what purposes is the *nitrate of silver* employed.
22. What is said respecting *fulminating silver* and other *fulminates?*
23. What is the nature of the article denominated *cinnabar?*
24. For what purpose is quicksilver used in gold and silver mines?

tin, and consists principally of the latter metal, which gives to it the requisite solidity(25).

There are two oxides, and several salts of mercury. The *protoxide* is of a black colour, and the *peroxide* red; the latter is commonly called *red precipitate.*

This red precipitate, when heated to ignition, gives out its oxygen, and returns to the state of metallic mercury. It is an article very interesting in the history of chemical discovery, as it was from this oxide that Dr Priestley first obtained oxygen gas(26).

Caroline. I think that you mentioned the freezing of mercury by the natural cold of some climates.

Mrs B. Yes, I did; although in order to its existing in the solid state it requires to have its temperature reduced thirty-nine degrees below the zero of Fahrenheit's scale. It is then not only a solid, but also a malleable metal. In Siberia, and some other countries, this degree of cold not unfrequently occurs; but in this climate, so low a temperature can be produced by artificial means only. When mercury has been frozen, a curious effect is produced by throwing a lump of it into a glass of water. The water will immediately become solid ice, and the mercury at the same moment will become fluid.

Caroline. Such an appearance is certainly very striking, but the cause is, I think, quite evident. The mercury will reduce the water below its freezing point; whilst the heat which the water gives out in becoming solid, will raise the temperature of the mercury sufficiently to bring this metal into the fluid state(27).

Mrs B. The first metals to which I called your attention, are usually esteemed the most valuable; but even gold and silver are, like every thing else, valuable only in their proper places. There is another metal, generally accounted very inferior to these, which, were utility made the only test of worth, would rank far above either of them.

Emily. IRON is certainly the most useful of all the metals, and is undoubtedly the one to which you allude.

Mrs B. And this metal, so essential to the arts of life, nature has diffused with a most bountiful hand. Traces of it are found in almost every soil, and in each of the kingdoms of nature ; and every country has its mines, whence iron may be obtained in abundance.

The existence of pure, native iron is doubtful. Masses of this metal, some of which weigh several tons, have been discovered in various places ; but as they are not generally in the vicinity of iron mines, and all of them resemble the meteoric iron, in being alloyed with nickel, they are(28)supposed to have fallen from the higher regions of the atmosphere.

Caroline. After the evidence of the fall of meteorolites, containing a large portion of iron, I do not see why tons may not fall from the heavens, as well as pounds. My faith, therefore, does not stagger under the weight of this ponderous supposition.

Mrs B. Iron is less malleable, but more ductile, than either gold or silver. It may be drawn into wire finer than a human hair, and which will support a weight considerably greater than a wire of the same size formed of any other metal. Although in the impure form of cast iron, it is readily fused and poured into moulds, yet, when in its pure state, iron is melted with difficulty(29).

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25. Of what does the silvering on looking glasses consist?
26. What observations are made on the oxides of mercury?
27. Narrate the facts mentioned respecting the freezing of mercury.
28. Is *iron* generally diffused, and is it ever found native?
29. What is said respecting the ductility and fusibility of iron?

Emily. It seems that the metals in a state of mixture always fuse more readily than when pure. With what is cast iron alloyed?

Mrs B. Cast iron does not, as you seem to suppose, owe its fusibility to the presence of another metal, but to that of a very different body; to carbon, between which and iron there is a strong affinity(30).

Caroline. I should certainly never have suspected such a combination as that; but it is not surprising that iron should lose its tenacity, by combining with so fragile an article as charcoal.

Mrs B. This is the principal, though not the only impurity in cast iron; and the art of refining it consists in the removal of these foreign matters. You are aware that iron and steel are essentially alike, are you not?

Caroline. I have supposed that steel was highly refined iron; or I ought rather to confess that my ideas upon this subject have been very vague. I plainly perceive that my supposed familiarity with the nature of certain bodies, has had the effect of preventing those inquiries which would have made my knowledge real, instead of imaginary.

Mrs B. *Steel,* like cast iron, contains a portion of carbon, and is, therefore, a *carburet of iron.* But in this state the iron is free from all other impurities, and the quantity of carbon which is combined with it, is but small, although all the peculiar properties of the steel result from its presence.

Steel is prepared by taking bars of fine malleable iron, and imbedding them in pulverized charcoal, in a kind of oven, built for the purpose. This oven is closely stopped up so as to exclude the air of the atmosphere: it is then surrounded by fire, and its contents brought to a red heat. After being kept in this condition for three or four days, the bars will be found to have absorbed a portion of the carbon, which will have made a sensible addition to their weight. The iron has now become steel; and if one of the bars is heated to redness, and suddenly cooled by plunging it into cold water, it will be rendered extremely hard. It is this property which qualifies steel for being made into knives, scissors, axes, and all the various kinds of cutting instruments.

The process by which iron is converted into steel is called *cementation*(31).

Caroline. Had not the effects of chemical combination been rendered familiar to us, by what we have previously learnt, the assertion that iron is rendered capable of becoming extremely hard, of bearing a fine edge, and receiving a beautiful polish, merely by its combination with charcoal, would have appeared incredible; but this fact seems only to add one other to the list of evidences which prove that the sensible properties of chemical compounds are independent of those of their constituents.

Mrs B. Were further proof of this general truth necessary, there is a substance composed of the same materials with steel, which might aid in establishing it. The substance to which I allude is black lead.

Emily. Guided by the name and appearance only, I have always supposed that black lead was some compound of the metal from which its name is derived.

Mrs B. Neither the name nor appearance afford any correct indication of its nature, as it does not contain a single particle of lead, but consists of carbon, nearly pure, combined with four or five per cent. of iron. This, therefore, is also a *carburet of iron.* In mineralogy it is known by the names of *plumbago* and of *graphite*(32).

With one of the most important salts of iron, the sulphate, you have

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30. To what does cast iron owe its fusibility?

31. In what way is iron converted into steel, and what is the process called?

32. What names has another substance which is a carburet of iron?

already some acquaintance; the others I shall leave you to study at your leisure. The property of welding, which belongs to this metal, enhances its value a hundred fold, and is another of those simple provisions of nature which, in so many instances, have left upon her works the impress of design and benevolence.

One other circumstance respecting iron must close our notice of this metal; I mean its property of being attracted by the magnet, and of being itself rendered permanently magnetic.

Caroline. But does not this power reside originally in the mineral called the *loadstone.*

Mrs B. The natural magnet, or loadstone, is an ore of iron, and derives its magnetism entirely from the presence of this metal; but artificial magnets, made of steel are more powerful than any of those supplied by nature. There are two other metals that are capable of becoming magnetic: these are *nickel* and *cobalt*(33).

Copper, to which we will now attend, is perhaps second only to iron, in usefulness.

Native copper is frequently found. In the neighbourhood of Lake Superior, there are enormous masses of it so perfectly malleable, that it can be wrought without being first fused and refined. Although native copper is by no means rare, the metal is usually found mineralized, and there are but few which exist in a greater variety of combinations than this. Many of its ores exhibit beautiful colours; these are frequently, though not by any means uniformly, green or blue(34).

Emily. And I believe most of its salts are of these colours. The *sulphate of copper*, or blue vitriol, and the *nitrate of copper*, which is green, you have already shown to us. The *verdigris*, too, that forms upon our copper saucepans, is always of one or other of these colours(35).

Mrs B. There is but one salt of copper, properly named *verdigris*, and this consists of *acetic acid* (vinegar) united to the oxide of copper. Every salt of copper which accidentally forms upon the utensils employed in our kitchens, is called verdigris, but, in most instances, improperly(36).

Caroline. I believe, however, that there is one general truth respecting them all, which is no mistake, and that is, that they are very poisonous.

Mrs B. In giving a summary of the properties and uses of copper, it will be quite safe to commence with your observation. Its salts are all poisonous. It has a red colour, which distinguishes it from all other metals, excepting *titanium.* In a dry atmosphere it undergoes very little change; but when heated, is rapidly oxidized. It forms a component part of the alloys called brass, bronze, pinchbeck, bell-metal, and several others. With the exception of steel, an alloy of copper and tin forms the best cutting instruments, and was used for this purpose by the ancients(37).

You may now, if you have any choice, name the metal to which we shall next attend.

Emily. Lead, it seems to me, may claim to come next in order, if we give a preference to the property of usefulness.

Mrs B. I think your remark a correct one, as many valuable purposes are answered, not only by the pure metal, but by its salts and alloys.

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33. What is said of the magnetism of iron, and to what other metals may this property be communicated?

34. What is said of *native copper*, and of its ores?

35. What are the usual colours of the salts of copper?

36. What salt of copper is properly called *verdigris*?

37. What are the general properties and uses of this metal?

Caroline. I believe that these salts may be classed with those of copper, being very poisonous.

Mrs B. This is the case with so large a proportion of the metallic salts, that excepting in individual instances, where the contrary is known, it is most safe to treat them all as poisons(38).

Most of the lead used, is extracted from an ore called *galena*, which is a sulphuret of lead. Silver is very frequently found combined with this metal, and when its quantity amounts to four or five per cent, it is worth while to extract it, but not otherwise(39).

Caroline. Red lead, you informed us, is an oxide of this metal.

Mrs B. Yes. There are three oxides of lead; the protoxide, commonly called *litharge*, the deutoxide, called also *red lead*, or *minium*, and the tritoxide or peroxide, which is of a deep brown colour, and is frequently called the *puce coloured* oxide. These two last, when heated, give out oxygen, and are converted into the protoxide, or litharge(40).

Emily. White lead, and sugar of lead, are not, it seems, among the oxides; I suppose, therefore, that they are salts of this metal.

Mrs B. You are correct; *white lead*, or *ceruse*, is a *carbonate of lead*, and *sugar of lead* is the *acetate.* This last is formed by boiling either litharge or white lead in vinegar(41).

Following up Emily's idea of classing the metals according to their usefulness, I think that tin and zinc would next urge their claims, and perhaps with equal force. Without pretending to decide between them, we will first take some notice of *tin.*

I have already told you, that what is commonly called *tin*, consists of sheets of iron, covered with that metal.

Tin is extremely soft, and very malleable. It is beaten into leaves called tin foil, and may, in this way, be reduced to the one-thousandth part of an inch in thickness, which is by no means the limit of its malleability. When a bar of tin is bent, a peculiar crackling noise is heard, which is called the *cry of tin*(42).

Do you recollect the alloys of tin, which I formerly named to you?

Caroline. I remember two; *pewter*, which is usually made of tin and lead; and *bell-metal*, which is a mixture of tin and copper.

Mrs B. *Pewter* varies much in its composition; and is said sometimes not to contain any lead. Bell metal is a very brittle alloy, although both the metals of which it is composed are malleable.

Gold and some other metals are also rendered extremely brittle, when alloyed with tin.

Nearly all the tin used in the world is obtained from Cornwall, in England, or from Malacca, in India. It is the most fusible of all the metals in common use, melting at about 440° of heat. The *nitro-muriate* of tin is used in dying red morocco, and other articles, of a scarlet colour. The muriate is the principal salt of this metal used in the arts(43).

Emily. The next metal, Zinc, is not now new to us. Its use in the experiments on galvanism has made us familiar with its appearance, and its employment in forming with copper an alloy so much used as brass, certainly gives to it no small claim to consideration.

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38. What is a very common property of the salts of the metals?
39. What ore of *lead* is the most abundant?
40. Give the chemical and common names of the oxides of lead?
41. What is white lead, and what the sugar of lead?
42. What are the distinguishing properties of tin?
43. What are the common alloys and uses of tin?

Mrs B. In commerce, *zinc* is frequently known under the name of *spelter*. *Calamine*, which is a carbonate of zinc, and *blende*, which is a sulphuret, are its most common ores. The principal uses of this metal have been already noticed, and need not to be repeated(44).

Caroline. You sometimes employed it in preference to iron, when making hydrogen gas, and I then observed that the sulphate, left after the operation, crystallized in the flask. Is this salt of any use?

Mrs B. The sulphate of zinc is, in commerce, called *white vitriol.* It is used in medicine, and in the arts also, though principally to render paint drying. Nearly all the acids dissolve zinc, but its salts are generally unimportant(45).

Caroline. I have been a little astonished that the metals, many of which combine so greedily with oxygen, and form with it alkalies, earths, and oxides, should not, like the other simple inflammables, produce acids also.

Mrs B. Then you will not be surprised to learn, that there are several of the metals which do actually acquire acid properties by their union with oxygen. *Arsenic*, *tellurium*, *chrome*, *molybdena*, *tungsten* and *columbium*, all possess this character, and there are others, which, though less decidedly acidifiable, have yet some claim to admission into the same class(46). The most important of these is Arsenic.

Emily. I can scarcely hear the name of *arsenic* without feeling some alarm, it is so deadly a poison, and accidents with it have been so frequent. I had no idea, however, of its being a metallic body.

Mrs B. The article sold in the shops under the name of arsenic, and sometimes called the *white oxide of arsenic*, is *arsenious acid;* and united with a larger dose of oxygen, it becomes *arsenic acid.* These acids combine with a number of salifiable bases, forming *arsenites* and *arseniates*(47).

Arsenic is sometimes found native, but more commonly in combination with other metals. It is volatile, and when the ores which contain it are heated in furnaces, the arsenic is sublimed, combines with oxygen, and condenses into a solid mass within the chimney, whence it is taken in thick cakes. Metallic arsenic is used in conjunction with copper and tin in making the mirrors for reflecting telescopes. It renders their texture compact, their colour white, and makes the alloy susceptible of a finer polish(48).

Caroline. What is sold under the name of ratsbane is then arsenious acid; as ratsbane and arsenic, if I have been correctly informed, are the same thing.

Mrs B. They are so. But this article, although used for the destruction of vermin on account of its poisonous property, has formed a valuable medicine in the hands of the skilful practitioner. There are, indeed, few physicians who have not employed it.

Another of these metallic acids is now extensively used in the arts, the base of which is called *chrome.*

Chrome has been obtained in but very small quantities, as its reduction is extremely difficult. It is usually found acidified and combined with iron. The *chromate of iron* exists in large quantities at Unst in Scotland; in the United States, near Baltimore in Maryland, and in Chester county, Pennsylvania. It is principally used for the manufacturing of that beautiful colour called *chromic yellow*, which is a *chromate of lead.* A distinguishing

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44. What are the ores of *zinc*, and what are its principal uses?
45. What is *white vitriol*, and for what purpose is it employed?
46. Name the metals which may be converted into acids.
47. What is the nature of the *arsenic* of commerce?
48. How is arsenic obtained, and what are its uses?

characteristic of this acid is its property of communicating vivid colours to the metallic oxides.

Emily. I am acquainted with only one of its colours, and if it furnishes any others of equal brilliancy and purity, it is indeed a valuable article. Among all the yellows which I have used in my painting, there is not one which I think equal to the chromic yellow in its perfect freedom from every other tint(49).

Mrs B. ANTIMONY is the only remaining substance which is much used in the metallic state. The article sold under this name is the *sulphuret of antimony*, and is the ore from which the metal is obtained. To the metal itself the older chemists gave the name of *regulus of antimony*. It is sometimes found native, but is usually obtained from the sulphuret(50).

Antimony sometimes enters into the composition of pewter; and mixed with lead and bismuth it forms the metal of which printing types are made. It is from antimony that type-metal derives the requisite hardness, and the property of taking a fine, sharp impression in the mould. Its oxides also are employed for communicating a yellow colour to glass and to pottery (51).

Caroline. And some of its salts, I know, are used in medicine. The names of tartarized antimony, and of antimonial wine, plainly indicate that the articles to which they are given are antimonial preparations.

Mrs B. The preparations of antimony, and of some other metals which were introduced into medicine by the alchemists, supply the physician with some of the most active and most useful of his antidotes to disease; for although many of them are strong poisons, it is to this very circumstance that we are indebted for their power to counteract disease, when administered by the hand of skill and experience(52).

Emily. The oxides and salts of the metals appear likewise to furnish the greater number of the colours used in painting. I had no idea that so many of them were metallic.

Mrs B. I have mentioned but a very small proportionate number of the metallic pigments, because I would not fatigue you with a mere catalogue. For the same reason I have merely named some of the metals, as they are studies for the closet rather than subjects for our conversations. The *oxide of manganese* is much used in the process of bleaching; a fact which will be more particularly noticed when we treat of *chlorine*. COBALT furnishes that beautiful blue colour called *zaffre*, or *smalt*, used for making blue glass, colouring pottery, and other purposes. The pearl white, sometimes employed as a pigment by the ladies, is an oxide of bismuth, the metal which you may recollect enters into the composition of what is called the fusible alloy, melting at the temperature of boiling water(53).

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49. What is *chrome*, and what its most useful preparation?
50. What is said respecting the sulphuret and the *regulus of antimony?*
51. To what use is antimony applied in the arts?
52. What remarks are made on the medical use of metallic preparations?
53. What is said of metallic pigments or colours?

CONVERSATION XX.

ON AFFINITY, AND THE LAWS WHICH GOVERN CHEMICAL COMBINATIONS.

Action of the Voltaic Battery upon Alkaline Salts. Acids passed through Alkaline Solutions, without combination. Nature of Chemical Affinity. Laws by which it is governed. Double Elective Attraction. Law of Definite Proportions. Atomic Theory. Combination of Gases by Volumes. Newton's Opinion respecting ultimate Particles or Atoms. Relative weight of Atoms. Comparison of the absolute and relative weights. Practical advantages of the Law of Definite Proportions.

Mrs B. You are aware, young ladies, that it was my intention to resume the subject of CHEMICAL AFFINITY at some convenient period. The time has now arrived when I think it may be done with great advantage. We have examined the greater number of the simple, or elementary bodies, and have traced them into many of their combinations. In doing this, it has been necessary to notice, incidentally, some of the principles by which these combinations are governed; but you are now sufficiently familiar with the most important chemical agents, to understand those more recondite laws, the existence of which has been discovered by the laborious researches of the chemist.

Caroline. I need not inform you that I am much pleased with inquiries of this description. I think, however, that my too ardent zeal for speculation has been, to a considerable extent, corrected by the kind manner in which you have so repeatedly placed me in the wrong, when I have endeavoured to form theories, instead of acquiring a knowledge of experimental truths.

Mrs B. I have been much gratified, my dear girl, to observe your gradual but steady approach towards a just estimate of the value of facts, and a conviction of the necessity of an intimate acquaintance with all those which have been discovered, relating to any subject, before an attempt is made to connect any of them together by a theory.

Emily. I am very glad, Mrs B. to observe that you have prepared the voltaic battery, and are about to exhibit some experiments with it. Its power of decomposition is so remarkable, as to connect it very intimately with the subject of chemical affinity.

Mrs B. You have witnessed the facility with which the elements of water are separated from each other, by the attraction of its opposite poles, and you have been informed of other decompositions, still more remarkable, which are effected by the same means; one or two of these it is my purpose to exhibit to you.

Caroline. And can you decompose the more complex substances in the same way in which you decompose water, which consists of two elements only? Can you, for example, separate the acid from the alkali in a salt, by means of electricity?

Mrs B. Very readily. We will take some of this solution of sulphate of soda, (Glauber's salt,) and subject it to the action of the battery: you will find that the alkali will be attracted by the negative, and the acid by the positive wire, with a force sufficient to separate them from each other(1).

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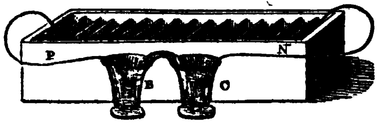
1. How will the voltaic battery affect an alkaline salt?

By the arrangements which I have made, we can collect the products of the decomposition in separate vessels, as we formerly did the oxygen and hydrogen, when we decomposed water.

Alkaline Salt decomposed by Electricity.



I have two cups, into one of which [C] I have poured the solution of Glauber's salt; into this likewise dips the platina wire [N] from the negative pole of the battery. The other cup [B] contains water, and is connected with the positive pole, by the opposite wire [P]. A piece of moistened cotton wick forms a conducting communication between the two cups. The attraction of the positive pole for the acid, will cause it to leave the first cup [C], and pass along the cotton wick, into the water of the second cup [B], where it will be found in solution; whilst the alkali will be detained in the first cup [C], by the attraction of the negative pole for that substance. This cup, therefore, will, at the conclusion of the experiment, contain a solution of pure soda. I have had the experiment in progress a sufficient length of time to effect the object(2).

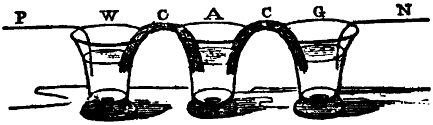
Emily. That does, indeed, manifest the astonishing power of electric attraction in overcoming chemical affinity. Observe, the blue vegetable infusion which you have dropped into one of the cups has become red, and that in the other green; showing, in the first, the presence of an acid, and in the second, that of an alkali.

Caroline. But what would have been the result, if each cup had been filled with the saline solution?

Mrs B. Just the same as at present. The acid of the first cup [C] would have passed into the second cup [B], and the alkali from that into the first cup [C]. All the sulphuric acid, therefore, would have been found in one cup, and all the soda in the other.

Caroline. Astonishing! They must then have actually passed each other in going along the cotton into their respective cups(3).

An Acid passed through an Alkaline Solution.



Mrs B. We can vary the experiment so as to render it still more striking, by using three cups, and putting into the central cup [A] an alkaline solution; the Glauber's salt being placed in the negative cup (G), and the positive cup (W) containing water only. The acid will be attracted by the positive wire (P), and will actually appear in the vessel (W), after having passed through the alkaline solution contained in the centre cup (A), without com-

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2. Describe the manner of conducting the experiment?
3. If each cup contained the salt, what would be the result?

bining with it; although, you know, acids and alkalies are so much disposed to unite(4).

Emily. It is no longer surprising to me, that the discovery of voltaic electricity should have greatly advanced the inquiries of the chemist into the composition of bodies, as the power of your apparatus, which you say is a comparatively small one, appears to be superior to that of chemical affinity, and sufficient to counteract the energetic attraction which subsists between sulphuric acid and the alkalies. What then may not be expected from those magnificent batteries of which we have heard you speak(5).

Mrs B. We must now examine those laws of combination which are to form the main subject of our inquiries to-day. Your attention has been so frequently called to the effects of chemical attraction, or affinity, that you cannot have forgotten what are the circumstances under which it is exerted, as formerly explained to you.

Emily. Certainly not; CHEMICAL ATTRACTION is that attraction which subsists between bodies dissimilar in their natures, and which occasions them to combine and form a compound possessed of properties different from those of the combining substances(6).

Mrs B. Very well; your definition comprehends what is sometimes called the first law of chemical attraction, namely, that *it takes place only between bodies of a different nature*(7).

Caroline. That we understand, of course; for the attraction exerted between particles of a similar nature is the attraction of aggregation or cohesion, and is independent of any chemical power.

Mrs B. Another law of chemical attraction is, that *it is exerted only between the most minute particles of bodies;* and hence it follows that *mechanical division promotes chemical action.*

Caroline. That is a circumstance which we might have inferred; for it is evident that the more fine we make the particles of different substances, the more easily and perfectly they will come into contact with each other, which, of course, must greatly facilitate their union. Indeed, we habitually practise upon this rule, as we always pulverize a solid when we wish to dissolve it rapidly in a fluid(8).

Mrs B. It is for this same reason that *bodies act most readily upon each other when one of them is in a state of solution.* It was, in fact, formerly laid down as a law, that bodies would not act chemically upon each other unless this was the case. There are, however, many instances known in which new combinations may be formed by the mutual reaction of substances which are in a solid and perfectly dry state(9). To produce this effect, such substances should be reduced to fine powder, and mechanical force employed to cause the particles to approximate.

Observe; I rub together, in this mortar, some muriate of ammonia and quicklime, both of them being quite dry. When separate, neither of these substances possesses odour; you may now find that the latter character is not retained by them.

Emily. What a powerful smell of ammonia, and so acrid it actually makes the tears run from my eyes. This is the same mixture by which you formerly obtained ammonia; and, of course, a muriate of lime is now formed by the union of the acid of the *sal ammoniac* with the lime(10).

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4. Describe the experiment as performed with three cups.
5. What is remarked respecting the power of electrical attraction?
6. What is affinity, and between what bodies is it exerted?
7. What is the first law of chemical attraction?
8. What is the next law, and what is said respecting it?
9. What is observed respecting the effect of solution?
10. What experiment with *sal ammoniac* and quicklime is mentioned?

Mrs B. There are also many explosive powders which ignite by a very slight friction, and which might, therefore, be fairly presented as exceptions to the rule advanced by the older chemists(11).

Another law of chemical attraction is, that *combination may take place between two, three, four, or even a greater number of substances.* This law you have seen fully exemplified in the formation of several saline bodies, as well as in other instances; and indeed, I am sure that as these laws are presented to you, you will observe that I am only bringing together rules with which you have already some acquaintance. I have been careful to notice most of them, whenever they were experimentally illustrated(12).

Emily. And I am sure that we shall derive great benefit from a systematic repetition of these laws which have hitherto been presented to us as isolated facts.

Mrs B. That *a change of temperature always takes place at the moment of combination* is a very important law, and one of which your recollection will readily furnish many examples(13).

Caroline. The simple fact, that a change of capacity for caloric occurs whenever bodies combine chemically, must, of necessity, render this law universal. There is so generally a change of form, too, when bodies combine, that this circumstance alone would account for a change of temperature(14).

Mrs B. Recollect, however, that a change of form is not necessary to a change of temperature. When I poured cold sulphuric acid and water together, the mixture remained fluid, yet the temperature was raised to upwards of three hundred degrees, which is far above that of boiling water; but although the form remained unchanged, the mixed liquids were more dense than in their separate state, and their capacity for caloric was consequently decreased(15).

I will here repeat another law, although it is included in Emily's definition of chemical attraction; it is this: *the properties which characterize bodies when separate, are modified, or completely changed, by their combination.*

Emily. The evidences of that law meet us every where. What can differ more completely than water does from oxygen and hydrogen gases; or what can resemble sulphur, oxygen, and iron less than does common copperas, the sulphate of iron(16).

Mrs B. The law that *a body possessing an attraction towards a number of others, possesses it in different degrees,* was explained to you in our first conversation, (p. 22,) and you cannot have forgotten the tables of *simple affinity* which the chemist constructs to exhibit this fact. The principle upon which these tables depend is expressed in the law, that *the force of chemical affinity between the constituents of a body is estimated by that which is required for their separation*(17).

Caroline. I should find it difficult to conceive how there could, in fact, be any other measure of this force; and certainly the decompositions which the chemist effects must depend upon his knowledge of this difference in the force with which bodies attract each other. The tables of simple affinity must be a most perfect guide to him in effecting his operations(18).

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11. What other compounds illustrate the same fact?
12. What is said on the combining together of several different bodies?
13. What is the law respecting a change of temperature?
14. What are the observations made on this point?
15. What remarks are made respecting sulphuric acid and water?
16. What is the law relating to a change in the properties of bodies?
17. What respecting the affinity of a body for several others?
18. What are Caroline's observations regarding this law?

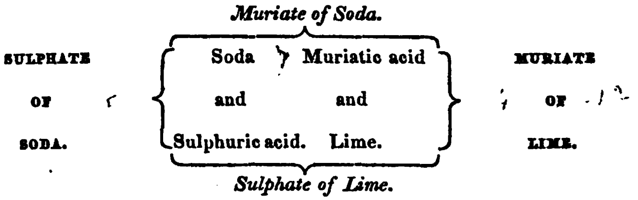
Mrs B. You estimate the utility of these tables too highly. Whenever the decomposition of a body can be effected by the addition of a single new substance, the change is said to take place by *simple affinity*, and then such tables are very useful; but it often happens that no single substance will decompose that upon which the chemist wishes to operate, and he finds it necessary to add to it another compound body, in order to effect his purpose. In this case, both the compounds will be decomposed by the mutual interchange of their constituents, and two new compounds will be formed. All instances of this kind are said to result from DOUBLE ELECTIVE ATTRACTION, or *complex affinity*(19).

Emily. Was not the decomposition of water by phosphuret of lime, a case of this kind? (p. 145.) Both the water and the phosphuret of lime were decomposed, whilst phosphuretted hydrogen, and phosphate of lime were produced.

Mrs B. This was an instance of the exertion of complex affinity; but my present object will be best attained by an example of the mutual decomposition of two salts. This you will easily comprehend by the assistance of a diagram, or table, which will very distinctly present an example of *double elective attraction*, together with some collateral circumstances accompanying the decompositions effected by it.

These diagrams are variously constructed, but after understanding one of them, you will find no difficulty with others, although they may be differently arranged.

The two compounds which I have chosen for an example, are the *sulphate of soda*, (Glauber's salt), and *muriate of lime*, a salt which, as its name indicates, is composed of lime and muriatic acid. If these two be mixed together in a state of solution, they will both be decomposed. The bases will exchange acids, or, if you please, the acids will exchange bases, and two new salts will be formed. This is the table(20).



Caroline. I seem, from the mere view of your diagram, to have acquired some insight into the plan of such tables, although I am not quite vain enough to attempt an explanation of it, and of the attractions which it is meant to exemplify.

Mrs B. On the outside of the vertical brackets you have the names of the original salts, and on the inside the name of the acid and base composing each of them. Above and below are the new compounds produced by their decomposition. The soda unites with the muriatic acid, and forms *muriate of soda* (common salt); and the lime with the sulphuric acid, producing *sulphate of lime* (plaster of Paris)(21).

Emily. This diagram certainly renders the double decomposition of these salts quite clear; and it is plain that if one of them is decomposed, the other

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19. What remarks are made on *double elective attraction?*
20. What are the substances chosen to exemplify such attractions?
21. Describe the table for exemplifying complex affinity.

must be so also. But is there any particular reason for placing the muriate of soda above, and the sulphate of lime below?

Mrs B. Yes, a very sufficient one. Before mixture, both salts were in solution; but their decomposition has produced one soluble salt, the muriate of soda, and one which is insoluble, the sulphate of lime. The solubility of the former is intended to be shown by its being placed above, with the bracket pointing upwards. The precipitation of the latter is indicated by its being placed below, with the bracket pointing downwards(22).

Caroline. If lime alone had been added to the sulphate of soda, would not a sulphate of lime have been formed? Or if, instead of that, muriatic acid had been added, would not a muriate of soda have been produced by simple affinity?

Mrs B. The sulphate of soda would, in either case, have remained undecomposed; as neither the attraction of sulphuric acid for lime, or of muriatic acid for soda, would have equalled that existing between sulphuric acid and soda. But when the two operate together, the decomposition is effected(23).

Emily. This seems a little like the adhesion of two articles which have been cemented together too firmly for the strength of one man to separate them, but which might be drawn asunder by the power of two men; when each of them would obtain a share of the spoil(24).

Caroline. There is a circumstance in chemical combinations, respecting which I have repeatedly thought of making an inquiry. The same bodies unite in different proportions; as, for example, oxygen and the metals. We may have a *protoxide*, a *deutoxide*, and a *tritoxide*, but we hear nothing of the intermediate states. Yet, if it requires a certain quantity of oxygen to form a protoxide, and double this quantity to produce a deutoxide, there must be a period when the metal is passing from one state to the other, and in which it must be half way between them(25).

Mrs B. The solution of this difficulty will lead us to the discussion of some points, which, although intricate, are yet of too much importance to be allowed to pass unnoticed. You must acquire some clear ideas respecting what is called the *law of combination in definite proportions*, and the *atomic theory of the chemical constitution of bodies.* These two subjects are intimately connected with each other, and are necessary to the understanding of the phenomena of chemical attraction(26).

There are some bodies which combine in all proportions; as alcohol and water, or sulphuric acid and water. One drop of the acid or of the alcohol will diffuse itself through a gallon of water, or one drop of water through a gallon of either of them. But in this, as in all such cases, the substances are united by a very feeble attraction, and the properties which characterized them when separate, undergo but little change by their union; resembling in this particular a state of simple mixture(27).

The law of COMBINATION IN DEFINITE PROPORTIONS applies to every case of energetic chemical attraction; that is, to all cases in which the properties of bodies are considerably altered by combination. The law is this; *a compound substance, so long as it retains its characteristic properties, must always consist of the same elements united together in the same proportions*(28).

Emily. I think that this truth is almost self-evident. For, if it requires a certain quantity of an alkali to neutralize a given quantity of an acid, the

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22. How may it indicate the solubility or insolubility of a salt?
23. Why would not lime alone decompose the sulphate of soda?
24. What simile is used to illustrate such double decompositions?
25. What inquiry is made respecting the formation of oxides?
26. What law and theory are involved in the reply to this inquiry?
27. What is said of bodies uniting in all proportions?
28. How is the law of combination in *definite proportions* announced?

combination of a greater or a smaller proportion could not produce a neutral salt. A part of one or other of the ingredients must remain uncombined, or else a new kind of salt must be formed. When oxygen and hydrogen gases were made to combine and form water, you took two volumes of hydrogen to one of oxygen, both of which disappeared entirely; but had you employed a larger proportionate quantity of either, this excess would have remained in the gaseous state after the explosion. You told us that such would have been the fact, and it appeared perfectly natural(29).

Mrs B. I was fully aware that this law would present no difficulty to you. You have mentioned the union of oxygen and hydrogen forming water: do you recollect that there is another combination of these principles?

Caroline. Perfectly well. It is called the *deutoxide*, or *peroxide of hydrogen.* I remember, also, that when compared with water it contains just twice as much oxygen in proportion to the hydrogen. In decomposing this peroxide, therefore, we should obtain equal volumes of oxygen and hydrogen. There is certainly something remarkable in this, if it be not purely accidental(30).

Mrs B. So far from being accidental, it is believed to be an individual example of a law which is universal; namely, that *when gaseous substances unite together, the volumes of the combining gases always bear a simple ratio to each other*(31). Thus, to form water, one volume of oxygen unites to two of hydrogen. To form the deutoxide of hydrogen requires equal volumes of the gases. When nitrogen combines with hydrogen, and produces ammonia, the combination is in the proportion of one volume of the former gas to three of the latter. And when sulphurous acid is converted into sulphuric acid, it is by the condensation of two measures of the acid gas and one of oxygen(32).

I might in this way go through the whole catalogue of those gases which combine chemically with each other, and show you that their union always takes place in definite proportions, and in volumes which may be measured by the same standard.

Emily. I think I now understand this law of definite proportions very well, so far as it regards the union of the gases, as of oxygen with hydrogen, and of hydrogen with nitrogen, in the instances you have just mentioned; but in the case of acids and alkalies, when the bodies are either liquid or solid, I do not perceive how their bulks or volumes can be measured in order to ascertain the proportion in which they combine.

Mrs B. Your observation is quite in point: the fact is, that the law of combination *by volume*, does not prevail in regard to liquids and solids. In these we must leave the circumstance of bulk entirely out of consideration. It is to their *weight* that we must attend, in determining the proportions in which they combine; and, accordingly, if we take the combining substances in a state of perfect purity, and ascertain with great accuracy, once for all, the proportions *by weight* in which they unite, we shall find that in every other instance where these substances have an opportunity of combining, so as to produce the same compound, they will unite in the same proportions and in no other. If the same principles form other compounds, their union will be in such proportions that one of the bodies shall be, in weight, exactly double, triple, quadruple, or in some other exact multiple ratio, to what it was in the former combination(33).

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29. What considerations render the truth of this law manifest?
30. What is noticed respecting the combinations of oxygen and hydrogen?
31. What is the law relating to the combination of gases?
32. What examples are given of the truth of this law?
33. How does the law of definite proportions apply to solids?

The apparent exceptions to this law have been continually decreasing in number, as more perfect methods of analyzing bodies have been discovered, and in the minds of intelligent chemists, not a doubt remains of its universality.

Caroline. This law requires a good deal of attention to be well understood. The examples you have given us as regards the gases, appear sufficient to establish the fact of their combining in measured volumes; and I have no doubt you will furnish testimony equally satisfactory respecting liquids and solids. I should like to know, however, whether any rational theory has been devised to account for these facts. Believe me, I have not now the temerity to inquire whether the cause is known.

Mrs B. Your wish is equally natural and proper, and, as far as my ability extends, it shall be gratified. The attraction of composition, you know, takes place only between the minute constituent particles of bodies, that is, among what has been sometimes called their *ultimate atoms.* Assuming this as a fact, and admitting that all bodies consist of ultimate atoms, which are in their natures indivisible, Mr Dalton, a very eminent English chemist, has proposed and advocated, with great ingenuity, what is called the ATOMIC THEORY(34).

Emily. Although I am aware that matter is divisible into particles inconceivably minute, yet I cannot form any idea of one of these particles which is not, in imagination at least, capable of being divided into halves or quarters(35).

Mrs B. It is believed by many philosophers, with Sir Isaac Newton at their head, that matter is composed of *ultimate particles*, or *atoms*, which are in their nature infinitely hard, and indivisible; that by the aggregation of such atoms similar in their natures, simple bodies are produced, and that by the combination of such as are dissimilar, compounds are formed(36). Thus a mass of lead consists of innumerable atoms of lead; and a mass of oxide of lead is formed of such atoms of lead, combined with atoms of oxygen.

You can very readily conceive that one atom of lead may unite with one of oxygen, and produce one *compound atom*, which will of course be an oxide of lead. But as the simple atoms are *ultimate*, or indivisible, the atom of lead cannot combine with one and a fifth of oxygen, although it may unite with two, three or four atoms(37).

Caroline. I am delighted with the simplicity and the clearness of this theory, and although you may not allow me to adopt it as absolutely true, I cannot help believing in it already. One atom of lead uniting with one of oxygen, would of course form a protoxide; if it combined with two of oxygen, a deutoxide would result, and if with three, the combination would produce a tritoxide. Really I do not see how so perfect a theory can admit of a doubt(38).

Mrs B. It is because it is not susceptible of absolute proof. We speak of ultimate atoms, and admit their existence to be highly probable, but further than this we cannot go; we cannot examine these ultimate atoms, millions of which may be contained in the smallest visible particle of matter. Renewing, therefore, my caution on the subject of theory, I shall in future freely use the terms *atom* and *atoms*, when speaking of the proportions in which bodies combine, without intending either to assert or to deny the correctness of the atomic theory(39).

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34. On what assumption is the *atomic theory* founded?
35. What remark is made on the divisibility of particles?
36. What was the opinion of Newton respecting *ultimate particles?*
37. What is said of the combination of these ultimate particles?
38. What are the remarks of Caroline respecting this theory?
39. Why may not the truth of this theory be fully admitted?

Emily. It seems to me strange that the same law should not prevail in the combination of bodies, whether gaseous or solid; but that the former should combine in given proportions by volume, and the latter in given proportions by weight.

Mrs B. It is certainly a very curious and interesting fact, that the combining volumes of the gases always bear a simple ratio to each other. But you will readily perceive that these combinations are as truly governed by weight as are those of solids. Hydrogen and oxygen unite in given proportions, and form water. When the deutoxide of hydrogen is to be produced, its formation requires a double bulk or volume of oxygen, which is evidently the same thing as a double weight of it. In treating of the gases, therefore, it is as proper to speak of their combination in proportionate weights, as it is to represent them as uniting in proportionate volumes(40). Water is believed to consist of one atom of hydrogen united to one atom of oxygen; and as the fluid produced by their combination weighs just nine times as much as that of the hydrogen employed, it thence follows that the weight of one atom of oxygen must exceed that of the atom of hydrogen eight fold. Were we, therefore, to represent the weight of an atom of hydrogen by the number one, the weight of an atom of oxygen would be represented by the number eight(41).

Caroline. But, Mrs B., how can you speak of weighing atoms, after admitting that they are inconceivably minute. They must be, practically at least, as imponderable as light and heat themselves?

Mrs B. I did not, my dear, speak of *weighing* atoms, but of the *relative weight* of atoms. If I tell you that water is 800 times heavier than air, I communicate a definite idea, although I say nothing of the absolute weight of either. If the constituents of water unite atom to atom, each atom of the fluid must consist of one atom of oxygen and one of hydrogen; and these compound atoms, by their accumulation, produce sensible portions of water. But the relative weights of the oxygen and the hydrogen must be the same, whether contained in a single compound atom, or in the ocean(42).

Hydrogen being the lightest body known to us in nature, its atom is generally made the standard with which all other bodies are compared(43). If we call the weight of the atom of hydrogen 1, that of oxygen will be 8, that of carbon 6, of sulphur 16, of potassium 40, and of lead 104(44).

Emily. The mode of calculating the relative weights of the atoms of oxygen and hydrogen appears to me quite satisfactory; but I am entirely at a loss to discover how the relative weights of other atoms can be deduced from these, particularly as there are many bodies with which hydrogen does not combine, as with lead for example(45).

Mrs B. This is a point which I cannot fully explain without devoting too large a portion of time to it. After supplying you with a general idea of the subject, I must trust to your pursuing and applying it in your future studies. But to remove your difficulty respecting hydrogen and lead; although these do not combine, yet oxygen and lead combine in several proportions; and if we can discover how many times the weight of an atom of lead exceeds that of an atom of oxygen, we can then tell also, how much it ex-

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40. What is observed respecting the combination by volume in gases, and by weight in other bodies?

41. How may the atomic weight of hydrogen and of oxygen be compared?

42. What is observed respecting the weighing of atoms?

43. Why has hydrogen been generally chosen as the standard of comparison?

44. What numbers represent the weight of certain atoms?

45. What difficulty is stated respecting the estimating of these weights?

ceeds that of an atom of hydrogen, one of these weighing exactly eight times as much as the other.

Caroline. I see plainly that by knowing the ratio which exists between oxygen and lead, and between oxygen and hydrogen, that between hydrogen and lead may be readily found.

Mrs B. When oxygen and lead combine, and form the protoxide of lead, which is believed to consist of one atom of each, every eight grains of oxygen will produce one hundred and twelve grains of the oxide. Now, if the weight of the atom of oxygen, which is represented by the number eight, be subtracted from that of the atom of protoxide of lead, which is represented by the number one hundred and twelve, one hundred and four will remain as the weight of the atom of lead(46). In forming the *peroxide* of lead, one hundred and four grains of the metal combine with sixteen of oxygen, and the compound will weigh one hundred and twenty grains. In this, therefore, one atom of lead has combined with two atoms of oxygen, and if this peroxide be heated to redness, it parts with half its oxygen, and becomes a protoxide(47).

Emily. In your illustration you speak of grains and of atoms, indifferently, as though one would serve to represent the other. I do not clearly perceive how this can be the case.

Mrs B. A little reflection will render it perfectly clear, and perhaps it will be best to recur to water for the purpose of illustration; and you can afterwards apply the same reasoning to oxide of lead, or to any other compound. Suppose you had a sufficient number of atoms of hydrogen to weigh one grain; if you know that an atom of oxygen weighs eight times as much as one of hydrogen, you would at once perceive that in eight grains of oxygen there must be precisely the same number of atoms as in one grain of hydrogen. Suppose the number of atoms in each, that is, in the eight grains of oxygen and the one grain of hydrogen, to be one million, then nine grains of water would contain two millions of ultimate atoms, one half of which number would be atoms of hydrogen, which, at the same time, would form only one-ninth part of the whole weight. Whether, therefore, we speak of atoms, grains, or pounds, the number one would still represent the weight of the hydrogen, and the number eight that of the oxygen(48).

In forming the protoxide of lead, consisting of one atom of each of its constituents, the weight of the lead is thirteen times as great as that of the oxygen, and therefore one hundred and four times as great as that of an atom of hydrogen. The numbers one, eight, and one hundred and four, will, consequently, represent their relative weights(49).

Caroline. I confess that I do not find this a very easy part of the subject; yet I am fully impressed with its truth and importance, and hope that further inquiry and reflection may serve to remove the veil which now partially obscures it.

Mrs B. I have no fears upon this point; for we shall have repeated opportunities of illustrating these atomic weights, which I shall be careful to embrace. To those I have just given, I will now add one other example in the two combinations of oxygen with carbon, carbonic oxide and carbonic acid. From these you will see why the atom of carbon is represented by the number six. Eight parts by weight of oxygen unite with six of carbon, and produce fourteen of carbonic oxide: this, in passing to the state of carbonic acid, absorbs

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46. How is the weight of an atom of lead deduced?

47. What is said of the peroxide and protoxide of lead?

48. How may the absolute weight of a compound, and the relative weight of its atoms be computed?

49. Why may the numbers one, eight, and one hundred and four, represent the relative weight of an atom of hydrogen, oxygen and lead?

eight parts more of oxygen, producing twenty-two of carbonic acid. The first is formed by one atom of oxygen=8, uniting to one atom of carbon=6, and producing one atom of carbonic oxide=14. Carbonic acid consists of two atoms of oxygen $8 \times 2=16$, and one atom of carbon=6, making the atom of the acid=22(50).

Caroline. But how can you be certain that the first combination consists of one atom of each; why may there not be two atoms of one, and one of the other?

Mrs B. It may be shown upon mechanical principles that the most energetic attractions will be those of particle to particle; and it is therefore perfectly fair to infer, that those chemical combinations which bodies have the greatest tendency to form, and in which they most resist decomposition, are of this kind, especially when we find such an inference borne out by fair reasoning, founded upon numerous experiments(51).

To preserve a recollection of the examples which I have given to you, I have set down the substances and their atomic weights in a tabular form, which you may examine at your leisure(52).

		Atomic Weight. of base.		*Weight of oxygen.*		*Weight of atom of compound.*
Water is composed of	Hydrogen	1,	Oxygen	8,	=	9
Deutoxide of hydrogen	do	1,	do	16, 2 atoms	=	17
Protoxide of lead	Lead	104,	do	8,	=	112
Peroxide of lead	do	104,	do	16, 2 atoms	=	120
Carbonic oxide	Carbon	6,	do	8,	=	14
Carbonic acid	do	6,	do	16, 2 atoms	=	22

For the sake of simplicity I have confined each of my examples to the combination of two simple bodies only, but the same law prevails in the formation of all compounds, however complex they may be.

Emily. And has the chemist been able to derive any particular advantage from the knowledge of the law of definite proportions?

Mrs B. Yes, and a very considerable one; for it enables him to form tables, by which he can see, at a glance, the composition of all the bodies which have been accurately analyzed, and ascertain in an instant what quantity of one body will be necessary to saturate, or to decompose, a certain quantity of another; and, in general, to construct tables which serve to present, in one view, the result of any chemical decomposition, and the quantities of the new compounds formed; by which means a considerable saving of labour is effected, whether in enabling us to calculate beforehand the results of any manufacturing operation, or in estimating those obtained in analytical processes(53). But I perceive the subject is becoming rather too intricate for us. We must not run the risk of entering into difficulties which might confuse your ideas, instead of throwing additional light upon this abstruse part of the philosophy of chemistry.

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50. Give the example of the combining proportions of oxygen and carbon.
51. When do we infer that a combination contains one atom of each of its constituents?
52. Give the atomic constitution of the compounds named.
53. What advantage is derived from the law of definite proportions?

CONVERSATION XXI.

ON THE COMBINATIONS OF OXYGEN AND NITROGEN.

Five Combinations of Oxygen and Nitrogen. State of the two Gases in the Atmosphere. Oxygen supplied by Growing Vegetables. Atomic Constitution of the Compounds of Oxygen and Nitrogen. Nitric Acid formed by Nature. Its production by the Electric Spark. Mode of obtaining it from Nitre. Charcoal and Spirits of Turpentine fired by it. Decomposition of Nitric Acid by Heat and Light. Uses of Nitric Acid.

Mrs B. When I inform you that our attention to-day will be devoted to the combinations of oxygen and nitrogen, you will probably think that we are retrograding instead of advancing in our chemical inquiries. You undoubtedly recollect, however, that in our conversation upon the subject of the atmosphere, but little was said respecting nitrogen or its combinations.

Caroline. And I must confess that this same nitrogen appeared to me to be so much of a passive being, that there was but little to say about it; all the active properties of the air manifestly depending upon its oxygen. We have since, it is true, met with nitrogen in one combination in which it assumes no insignificant character; for, certainly, as a component part of ammonia, it seems to be any thing but inert.

In recurring to nitrogen, which you have previously intimated enters into other active compounds, and contributes its full share to their properties, I feel that, notwithstanding the many examples which we have witnessed of the transforming power of chemical combination, I still find it difficult fully to realize its influence. I am, even now, scarcely prepared to anticipate the complete metamorphosis which it produces among our every day acquaintances, such as the air we breathe, and the water that we drink; although these are events with which you have made us in some degree familiar.

Mrs B. The most striking example of this thorough change of properties is, perhaps, that upon the examination of which we are now entering; as the component parts of the atmosphere, oxygen and nitrogen, unite together in five different proportions, forming as many well characterized compounds, three of which are acids, and two oxides(1).

Emily. The atmosphere, you have told us, is uniform in its composition; the proportionate quantities of oxygen and nitrogen being the same at all times and in all places. I have often thought of this fact, and have as often been at a loss to account for it. There are so many processes by which the oxygen of the atmosphere is separated from it, and made to combine with other bodies, that a constant variation in its amount might be expected.

Mrs B. The air of the atmosphere is not reckoned among the five compounds to which I have alluded, as it is generally believed, that, notwithstanding the uniformity of its constitution, the gases of which it consists are in a state of simple mixture(2). The arguments in favour of its being a chemical combination, rest upon the fact, that the oxygen is to the nitrogen precisely in the proportion of one to four, by volume, whilst their atoms are, in number, as one to two; agreeing in every respect with the law of definite proportions(3).

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1. How many chemical combinations are there of oxygen and nitrogen?
2. Is it believed that they are chemically combined in the atmosphere?
3. What circumstance favours the idea of their chemical combination?

Caroline. I should think this proof sufficient, as these exact proportions could not be the result of mere accidental mixture.

Mrs B. There was no doubt design in thus constituting the atmosphere. But abler chemists than we are have considered the proofs of simple mixture to be sufficient to establish the fact. If we take oxygen and nitrogen, and mix them in the proportions in which they are found in the atmosphere, the temperature will be unaffected, the specific gravity, and indeed all the sensible qualities of the mixture will be precisely those of common air. There is, consequently, not the slightest evidence that any chemical action has taken place(4).

Caroline. I find that I ought to have heard both sides of the question before giving my opinion. I should like, however, to know how nature supplies the oxygen which is lost in combustion, in respiration, and in other processes which decompose the atmosphere.

Mrs B. It is probable that growing vegetables are the principal, if not the only agents employed in effecting this purpose. During the day, a healthy plant absorbs carbonic acid from the atmosphere, and gives out oxygen. In the night, it is true, the reverse operation takes place, oxygen being absorbed and carbonic acid evolved, but still not in quantities sufficient to counteract the first effect(5).

As regards the other compounds of oxygen and nitrogen, you will find evidence enough of their chemical union. The gases of which they consist may be *mixed* together in the five proportions in which they can be made to combihe, but will not in this state acquire any of those properties which so strongly characterize them when their atoms haye united by chemical attraction(6).

Emily. I am glad that we have acquired some knowledge of the atomic theory, as it will undoubtedly enable us to trace these various combinations more perfectly than we could have done without such information.

Mrs B. That was my principal motive for deferring the consideration of these compounds until the present period, as they will serve to exemplify the use of this theory in a very satisfactory manner. The weight of an atom of nitrogen has been found to be fourteen; that of oxygen, you will recollect, is eight, hydrogen being one; or in other words, an atom of oxygen is eight times, and an atom of nitrogen fourteen times, as heavy as an atom of hydrogen(7). The compounds of nitrogen and oxygen increase regularly from one atom of nitrogen with one of oxygen, up to one of nitrogen with five of oxygen. They are exhibited in this table, which you should copy and preserve, until you recollect the numbers.

	Composed of		
	Nitrogen.		*Oxygen.*
1. Protoxide of nitrogen, or nitrous oxide,	1 atom	+	1 atom.
2. Deutoxide of nitrogen, or nitric oxide,	1 atom	+	2 atoms.
3. Hyponitrous acid, - - -	1 atom	+	3 atoms.
4. Nitrous acid, - - - - -	1 atom	+	4 atoms.
5. Nitric acid, - - - - - -	1 atom	+	5 atoms(8).

Caroline. And we, it seems, are inhaling, at every breath, the elements of all these different compounds. It appears a little surprising that two substances which are capable of uniting in so many different proportions, should still remain merely mixed together, as they do in the atmosphere.

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4. What are the facts which militate against this opinion?
5. From what source is the waste of oxygen probably supplied?
6. What is remarked respecting the five known combinations?
7. What is the atomic weight of nitrogen, hydrogen being one?
8. How are the compounds of oxygen and nitrogen constituted?

Mrs B. The repulsive agency of the caloric, which is combined with them in the gaseous state, completely counteracts their chemical attraction for each other. But when one or both of them are in the nascent state, they readily unite(9). Although oxygen and nitrogen are capable of forming these five several compounds, only one of them is known as a natural product, and that is the *nitric acid.* All the others are artificially obtained by the chemist in his laboratory; and, in most instances, by the direct decomposition of this acid(10).

Emily. All that is necessary to convert nitric into nitrous acid, must be to deprive the former of one-fifth of its oxygen; and it is plain that upon the same principle, all the other compounds may be obtained. This indeed is a most satisfactory illustration of the atomic theory(11).

Caroline. Nitrogen, from its combination with oxygen, would seem to claim a place among the combustibles, yet I have no recollection of any fact which shows that it is capable of being burnt, although it can be oxygenated in so many different proportions.

Mrs B. Nitrogen is a body which seems to stand alone in its relationship, both to combustibles and to supporters of combustion, as it cannot be classed with either. It does not support combustion; and whilst it unites with oxygen and with the other bodies which do support it, it does this without the disengagement of light and heat, which you know are the essential characteristics of combustion(12).

In examining the compounds of oxygen and nitrogen, we shall commence with the last upon the list, that is, NITRIC ACID. This acid, I have informed you, is presented to us ready formed by nature, and all the other compounds may be obtained by its decomposition, simply, as Emily observes, by depriving it of different portions of its oxygen. You ought to know, however, that the chemist can produce nitric acid by effecting the direct combination of its elements, as they exist in the atmosphere. If a mixture of oxygen and nitrogen be confined in a glass tube, and a succession of electric sparks be made to pass through the tube, the bulk of the gases will be found gradually to diminish, and after several thousand electrical discharges, a minute quantity of nitric acid will be obtained(13). This experiment was first performed by Dr Priestley, but we are indebted to the repetition of it by the eminent chemist Mr Cavendish, for the correct deduction that nitric acid is composed of the bases of oxygen and nitrogen gases(14).

Caroline. If the electric fluid causes the gases to unite, why is there not a portion of nitric acid formed in the atmosphere in a thunder storm, when the lightning repeatedly passes through it? We should be in a sorry condition if such a storm should at once convert the air into nitric acid.

Mrs B. There is no danger of this, my dear. The lightning can affect but a very small portion of the atmosphere; and it appears that many thousand discharges through the same portion are necessary to the production of the acid. The quantity of oxygen in the atmosphere, also, is too small to favour its formation, and if there were any produced in this way, it must be much too small a quantity to be perceptible(15).

Emily. You have formerly told us that what is called aquafortis is

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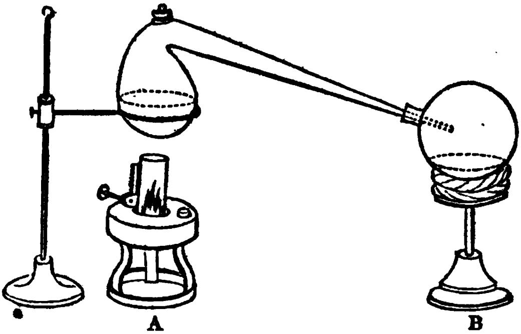
9. Why do they not combine in their state of mixture?
10. Which of these combinations is found ready formed in nature?
11. What observations are made on the production of nitrous acid?
12. What is remarked respecting the classing of nitrogen?
13. In what way may nitric acid be directly formed?
14. To whom are we indebted for this discovery?
15. Why is not nitric acid produced by lightning?

nitric acid. As this is extensively used in the arts, there must be some very ready means of obtaining it from its natural combinations, whatever they may be.

Mrs B. The salt which is known to you under the name of *nitre* or *saltpetre*, is, in chemical language, the *nitrate of potassa*, and consists of nitric acid united to potassa. It is from this salt that the acid is obtained. Sulphuric acid has so strong an affinity to potassa, that it will readily combine with it, and exclude the nitric acid. I will now exhibit the process by which nitric acid is procured; as several of the acids and some other compounds are obtained in a similar way(16).

You see that I use a retort and receiver, resembling those formerly shown to you. Into the retort I put a few ounces of nitre, and pour upon it about an equal weight of sulphuric acid; when I adapt a receiver to the retort, and apply heat to the materials contained in it. As the nitric is disengaged by the sulphuric acid, the heat will convert it into vapour, which will distil over; and as the receiver is kept cold, it will then be condensed into the liquid form(17).

Preparation of Nitric Acid.



[A, lamp placed under the retort, which contains *nitrate of potassa* (nitre) and sulphuric acid. B, stand supporting the receiver, in which the nitric acid is to be collected.]

I place the apparatus under the chimney, because a considerable portion of corrosive, uncondensable vapour will be disengaged in the process.

Caroline. Are we to consider aquafortis and nitric acid as identical, or is there any difference between them?

Mrs. B. Aquafortis is a weak, and, generally, an impure nitric acid; its strength being only one-fourth as great as that of the perfect acid. It received from the alchemists the name of aquafortis (strong water), in consequence of its effectually dissolving the greater number of the metals, as well as various other substances. Aquafortis is better adapted to many purposes in the arts than the pure acid, and it forms, therefore, a special article of manufacture(18).

Emily. You have already taught us something of the solvent power of nitric acid, and I believe you informed us that it is principally indebted for this power to the facility with which it parts with its oxygen.

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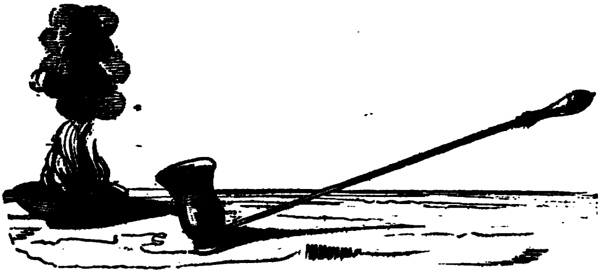
16. From what substance, and by what means is nitric acid obtained?
17. Describe the apparatus and the process employed.
18. What is said respecting nitric acid and aquafortis?

Mrs B. I did. This acid contains a larger quantity of oxygen than any other, and retains it by an attraction so feeble that it is decomposed by almost every substance having an affinity for it(19). Some which attract it strongly, will combine with the whole contained in the acid, and liberate its nitrogen in the gaseous form. Others, which act with less energy, take away a portion only of the oxygen, leaving the remainder in combination with the nitrogen, and thus producing one of the less oxygenated compounds(20).

Caroline. If nitric acid parts so readily with its oxygen, may it not actually produce combustion in those substances which are the most inflammable?

Mrs B. In most cases the decomposition is not sufficiently rapid to produce actual inflammation, although it does so in a few instances. If we take some perfectly dry fresh burnt charcoal, pulverize it, put it into a glass, and then pour upon it some of the strongest nitric acid, a vivid inflammation will ensue, and a suffocating vapour will escape, consisting of carbonic acid and the decomposed nitric acid(21). All the essential oils likewise may be inflamed by it. This effect I will exhibit to you, using the oil of turpentine. For this purpose I put some of it into a warm saucer; and, from a glass at the end of a long rod, pour on it strong nitric acid, the oxygen of which will unite to the oil with such rapidity as to inflame it. It is necessary to stand at a distance to avoid danger from the flame. The essential oils consist principally of hydrogen and carbon, and the oxygen of the acid unites with each of them in this combustion(22).

Spirits of Turpentine inflamed by Nitric Acid.



Emily. Have we any means of decomposing the nitric acid so as to convert it entirely into nitrogen and oxygen gases?

Mrs B. The very same means by which most combustibles are made to unite with oxygen and are converted into acids, will serve completely to decompose the nitric acid: I allude to a great elevation of temperature. If a portion of its vapour be passed through a red-hot tube of earthenware, it will be entirely converted into oxygen and nitrogen gases, which will be found mixed in the proportions before mentioned(23). Such is the quantity of oxygen thus produced, that a taper which has been just blown out, will be relighted if plunged into the mixed gases.

Even the light of the sun alone will produce a partial decomposition of nitric acid. That which I have in this bottle was as limpid and colourless as

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19. Upon what does the solvent power of nitric acid appear to depend?
20. How do different substances operate upon this acid?
21. What effect will nitric acid produce upon fresh burnt charcoal?
22. How may spirits of turpentine be inflamed by it?
23. In what way may nitric acid be completely decomposed?

water, when I first brought it from a dark closet into this room. It has already, you perceive, assumed a pale straw colour, and by continued exposure to light it will acquire a still darker hue(24).

Emily. But it has been kept closely stopped, so that nothing could escape from it into the air, nor could the air have access to it; and under these circumstances, it is difficult to see how a decomposition could be effected.

Mrs B. Had the glass been hermetically sealed, the same effect would have ensued. And it is evident that it is produced by light alone, as it does not take place in the dark, whatever change of temperature may occur. This fact seems to prove that light as well as heat is a constituent of oxygen gas, the gas being disengaged from the acid, and found occupying the upper part of the bottle(25).

If colourless nitric acid be put into a retort, the beak of which is placed under a receiver in the pneumatic cistern, the action of light will cause bubbles of oxygen gradually to escape, and to pass into the receiver, whilst the acid will become coloured. The source of this colour will be hereafter explained to you(26).

Caroline. As nitric acid, under the name of aquafortis, is so extensively used in the arts, it would be interesting to learn the purposes to which it is principally applied.

Mrs B. Its uses are numerous, but I can only give you a general idea of them. It is largely employed in refining, and many other operations on the metals. Most of the beautiful landscapes and other subjects printed from copper plates, are etched upon the copper by its means. In the hands of the dyer, it serves to fix and to heighten a variety of colours. In chemical processes, its uses are very numerous; and to the physician it is a valuable auxiliary in the cure of many diseases(27). We must now dismiss this part of our subject, and proceed to some of the substances produced by the decomposition of nitric acid. But as I have more to say respecting them than can well be included in one conversation, we will adjourn until tomorrow.

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24. What effect is produced upon this acid by light?
25. What proves that this change is produced by light alone?
26. How may the oxygen which light disengages be collected?
27. What are the principal uses to which nitric acid is applied?

CONVERSATION XXII.

ON THE COMBINATIONS OF OXYGEN AND NITROGEN (CONTINUED,) AND ON NITRATES.

Synthetical and Analytical Examination of Bodies. Nitrate of Copper. Nitric Oxide, Deutoxide of Nitrogen, or Nitrous Air. Nitrous Acid. Eudiometrical Property of Nitrous Air. Combustion in it. Absorbed by Nitric Acid. Aquafortis. Hyponitrous Acid. Nitrous Oxide. Formation and decomposition of Nitrate of Ammonia. Combustion in Nitrous Oxide. Its effects when inhaled. Table of the Compounds of Oxygen and Nitrogen. Nitrate of Potassa, Nitre, or Saltpetre. Nitrate of Lime. Nitre Caves. Incombustibility of Nitre. Oxygen Gas obtained from it. Deflagration. Gunpowder. Detonation. Fulminating Powder. Uses of Nitre. Properties of the Nitrates. Combustion of Tin Foil by Nitrate of Copper.

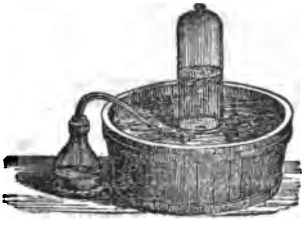
Emily. As there are five different combinations of oxygen and nitrogen, and you have commenced with the most powerful of the series, *Nitric acid,* I suppose that, proceeding by a descending scale, we are next to learn how to deprive this compound of one proportional of its oxygen, and thus to reduce it to the state of *nitrous acid.*

Mrs B. There are two modes of examining chemical substances; the synthetical and the analytical. When we proceed by the former method, we take the simples of which a body, under consideration, consists; combine these simples together, and obtain their product. By the analytical mode, we take a compound as it is presented to us; inquire into its properties, and then proceed to analyze it, that we may learn what are its constituents(1). We have hitherto pursued the former course, but in the present instance we shall adopt the latter. Proceeding regularly, the properties of *nitrous acid* would come next in order for our examination, but it will accord best with the course of our experiments to pass this by, until we have attended to the gas called NITRIC OXIDE, which we can readily obtain by depriving the acid of *three* proportionals of its oxygen.

Emily. We shall be perfectly satisfied to follow, in whatever course you may choose to lead us, as we are sure that it will be that which is best fitted for our instruction.

Mrs B. In our first conversation, I exhibited to you the experiment of dissolving copper in sulphuric acid, to which a little nitric acid had been added. By this means we produced a *sulphate of copper* (blue vitriol,) (page 19.) The use of the nitric acid in this case was to afford oxygen to the copper, which, when converted into an oxide, was dissolved by the sulphuric acid(2). I am now about to dissolve some copper in nitric acid alone; we shall by this means obtain *nitrate of copper.* This glass flask, or gas

Procuring Nitric Oxide.



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1. What are the two modes of examining chemical substances?
2. What is said respecting the production of *sulphate of copper?*

bottle, as it is called, I use instead of a retort. I have put into it some shreds of copper, and upon these I pour nitric acid a little diluted with water. This will immediately begin to act upon the copper with great power, and a quantity of gas will escape, which we will collect in a receiver in the usual way. A solution of nitrate of copper will remain in the bottle(3).

Caroline. This is the same mixture you made in our first conversation on the metals, (p. 185,) and I recollect that a very deep orange-coloured vapour escaped from it; but, in the present instance, the gas collected in the receiver is perfectly colourless(4).

Mrs B. You will soon learn the cause of this difference in colour. The gas which we have now collected is the *deutoxide of nitrogen*, or *nitric oxide*. Dr Priestley, its discoverer, called it *nitrous air*, a name still familiarly used(5). Water absorbs nitric oxide so sparingly, that it may be kept in contact with that fluid for any length of time. By recurring to your table, you will find that it contains two atoms of oxygen to one of nitrogen, and indeed its appellation of *deutoxide* indicates this fact(6). It has so strong an attraction for oxygen as to combine with it by mere mixture. If, therefore, we suffer it to come in contact with the atmosphere, it immediately loses its character as an oxide; for it instantaneously deprives the air of so much oxygen as to double its own portion, and thus assumes the form of NITROUS ACID. This acid, in its pure state, is also a gas, but one which is readily absorbed by water(7).

Caroline. Then I suppose that the orange red fumes which escaped in the former experiment were those of nitrous acid, and that the colour was produced by the union of the oxygen of the atmosphere with the deutoxide of nitrogen.

Mrs B. Your conjecture is perfectly correct. I will now incline the receiver on one side sufficiently to allow a bubble of the gas to escape into the atmosphere, and you will see that it instantaneously assumes a deep orange colour(8).

Emily. How curious! and yet the gas within the glass is perfectly invisible. This, however, would become coloured were you to admit a few bubbles of oxygen or atmospheric air, would it not?

Mrs B. Certainly; and to exhibit this effect, I will now mix with it a small portion of oxygen.

Emily. The whole volume of the gas has become coloured, and the water is rising rapidly in the receiver. This must be owing to the formation of nitrous acid, and its absorption by the water(9).

Caroline. Could you not add to this nitric oxide such a portion of oxygen as should convert the whole of it into nitrous acid? In this case I should expect to see the absorption complete, and the glass filled with water.

Mrs B. Were the two gases perfectly pure, and mixed in the exact proportions which form nitrous acid, the result would be such as you have supposed.

This effect is a very curious one; for, suppose the receiver to contain two pints of nitric oxide gas; if to this be added one pint of oxygen

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3. Describe the mode of forming a solution of the *nitrate of copper*.
4. What remark is made respecting this and a former experiment?
5. What gas is collected, and who was the discoverer of it?
6. Is *nitric oxide* absorbed by water, and what is its composition?
7. Describe the mode of converting it into *nitrous acid*.
8. What particular appearance accompanies the formation of this acid?
9. What effects are produced when oxygen is admitted into a receiver filled with this gas?

gas, instead of the quantity of air being increased by this addition, both the gases will disappear entirely(10).

Nitric oxide has been used in *eudiometry*, in consequence of its property of combining with oxygen; but the eudiometrical processes, which I formerly described to you, (p. 149,) have been found to be more accurate and convenient. The mode of employing the nitrous air will be suggested to you by the last experiment(11).

Caroline. From the quantity of oxygen contained in the deutoxide of nitrogen, I should apprehend that it would support combustion much better than atmospheric air.

Mrs B. Recollect that the oxygen is not free, but combined with nitrogen; and that nitrous air, instead of having a disposition to part with its oxygen, has a tendency to acquire more. Gases do not support combustion merely because they contain oxygen, but because they are ready to part with it. A burning candle, and indeed most other burning bodies are extinguished when immersed in the deutoxide. Some, however, which have a very strong attraction for oxygen, will decompose it. Phosphorus, for example, will burn in it very brilliantly, the products of the combustion being phosphoric acid and nitrogen(12).

The deutoxide of nitrogen is said to be irrespirable, and there is but little doubt of the fact; but this we have no means of ascertaining, as by mixing with the air contained in the mouth and lungs it becomes nitrous acid, which is extremely corrosive, and must quickly produce death from this cause, even if it did not from suffocation(13).

Emily. When nitric acid was decomposed by the action of light, the colour produced in it must have arisen from the formation of some nitrous acid by the abstraction of oxygen from the nitric acid.

Mrs B. Your conclusion is a very natural one, but not perfectly correct. When nitric acid is partially decomposed, it usually yields up so much of its oxygen as to pass into the state of nitric oxide, and this appears to be the case when light is the decomposing agent. The colour in the acid results, therefore, from the admixture of nitric oxide(14).

Caroline. But certainly there must be some nitrous acid formed, as is plainly indicated by the colour; nitrous air, being itself without colour, could not change that of the nitric acid.

Emily. Perhaps that is asserting a little too much, as we have seen colour produced by the mixture of two colourless articles, and may not that be the case in the present instance(15)?

Mrs B. It evidently is the case; for nitric acid will absorb a large quantity of nitrous air, and it changes its colour progressively as the absorption goes on. When the quantity of the gas is small, its hue is that of a pale yellow, and as the quantity increases it will become of a bright yellow, then a deep orange, and at last will appear green. Heat will expel the gas unchanged; and merely diluting the acid with water will produce the same effect(16).

What is found in commerce under the name of aquafortis, or nitrous acid, is usually coloured, and consists of nitric acid holding variable quantities of nitrous air in solution(17).

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10. How, and why, may both these gases be made to disappear?
11. For what purpose has nitrous air been sometimes employed?
12. How does this gas operate in supporting combustion?
13. What is said respecting its respirability?
14. How does light affect colourless nitric acid?
15. What is remarked respecting this production of colour?
16. How may it be proved that *nitrous air* produces the colour?
17. *Aquafortis* is generally coloured, from what does this proceed?

Caroline. How necessary it is to learn facts before we form opinions. But, Mrs B., according to our table, there is an acid intermediate between nitrous acid and nitric oxide, about which we have not yet learnt any thing.

Mrs B. Nor is there much for you to learn, as but little is known respecting the HYPONITROUS, or SUBNITROUS, ACID, as it is sometimes called. The existence of such a compound has been sufficiently proved, but it has not been obtained in an uncombined state, nor are there any facts respecting it which I think it necessary to detail(18).

Emily. Then the PROTOXIDE OF NITROGEN, or NITROUS OXIDE, will, I believe, complete our catalogue of these compounds. The *nitrous oxide* is the same with the *exhilarating gas*, which, when inhaled, produces such extraordinary effects, is it not?

Mrs B. It is. This gas was discovered by Priestley, but we are indebted to Davy for a full examination of its properties, and for the process by which it is obtained in a pure state(19). It was formerly procured by exposing nitric oxide to the filings of zinc moistened with water; or to some other substance which would deprive it of one-half of its oxygen. Zinc or iron, when dissolved in nitric acid, seizes upon so large a portion of its oxygen as to reduce it to the state of nitrous oxide. When procured, however, by either of these processes, it is always mixed with a portion of the *deutoxide*, which renders it irrespirable(20). But it can be obtained pure by decomposing a salt called the NITRATE OF AMMONIA, the name of which will, at once, suggest to you its composition, although it has never been explained to you.

Emily. How greatly we are indebted to this system of names, which it seemed at first so difficult to learn! *Nitrate of ammonia* must be a salt composed of nitric acid and ammonia, or the volatile alkali. As ammonia consists of hydrogen and nitrogen, and nitric acid of oxygen and nitrogen, the ultimate components of the salt must be oxygen, nitrogen, and hydrogen(21).

Mrs B. The crystallized salt in this phial is nitrate of ammonia. It may be produced by causing gaseous ammonia to pass into nitric acid. But the usual way of preparing it is to dilute nitric acid with three or four parts of water, and to drop into this mixture lumps of *carbonate of ammonia* (volatile smelling salts). An effervescence will immediately ensue, arising from the escape of carbonic acid, which is set free in consequence of the combination of the ammonia with the nitric acid. When this acid is saturated, the nitrate of ammonia may be obtained by evaporating the water with which the nitric acid was diluted(22). In order to decompose this salt a quantity of it is put into a retort, to which the heat of a lamp is applied. This will first cause it to fuse, and drive off a quantity of watery vapour. The fused salt will presently boil up in large distinct bubbles, and the whole of it will gradually be converted into nitrous oxide and watery vapour. The gas may be collected over water in the usual way(23).

Caroline. I thought that the watery vapour was to be driven off before the gas was produced; but you now speak of it as accompanying it through the whole process.

Mrs B. And so it does. For although you drive off the water originally contained in the salt, fresh portions of it are formed during the whole

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18. What is said respecting *hyponitrous acid?*
19. By whom was *nitrous oxide* discovered?
20. By what process was it at first obtained?
21. What is the composition of the salt which affords it in a pure state?
22. In what way may *nitrate of ammonia* be formed?
23. How is this salt decomposed to produce the nitrous oxide gas?

period of the decomposition. And a little reflection will, I am sure, enable you to discover its source(24).

Caroline. I think I perceive it now. The hydrogen of the ammonia must combine with a portion of the oxygen of the nitric acid, and thus produce water from its elements(25).

Mrs B. I was certain that you would discover this fact; and you must likewise perceive that this union of the hydrogen of the ammonia with a part of the oxygen of the acid, must produce the decomposition of both the constituents of the nitrate of ammonia. The atomic theory will aid you in tracing out these decompositions, as it will every other to which you are capable of applying it. The nitrate of ammonia consists of one atom of ammonia united to one atom of nitric acid. Ammonia is formed by the union of one atom of nitrogen and three atoms of hydrogen; and nitric acid of one atom of nitrogen and five of oxygen. What are the atoms, therefore, which enter into the composition of the nitrate of ammonia?

Emily. That is very easily calculated. There are three atoms of hydrogen, which are all supplied by the ammonia; two atoms of nitrogen, one from the ammonia, and the other from the acid; and five atoms of oxygen derived from the acid(26).

Mrs B. Certainly; and what will be the consequence should the three atoms of hydrogen combine with three of oxygen, and, by this combination, form three atoms of water?

Emily. It is very plain that two atoms of oxygen and two of nitrogen will be left.

Caroline. And it is equally plain that these are the elements of the protoxide of nitrogen, or nitrous oxide, which consists of oxygen and nitrogen, united atom to atom. And, as in the decomposition of the salt, they are presented to each other in their nascent state, they of course combine and produce the gas in question. How curious, how admirable, and how satisfactory, are these investigations! How well they repay the trouble of a thorough examination(27)!

Mrs B. Nitrous oxide differs very materially from nitrous air. It is very readily absorbed by water, which takes up its own bulk of this gas. A taper will burn in it more brilliantly than in atmospheric air, and iron wire undergoes combustion in it very brilliantly. Sulphur is extinguished by it, if it is introduced whilst burning with a feeble blue flame; but if well ignited with a white flame, its combustion will be rendered more vivid(28). If oxygen be mixed with it, no new combination takes place, as is the case with nitric oxide.

This gas is not only respirable, but is a very powerful stimulant, producing extraordinary effects upon the system.

Emily. I have never witnessed the breathing of it, nor have I any idea how this is managed. For myself, I confess that I should be unwilling to inhale it, if the accounts which I have heard of its effects have been correctly given.

Mrs B. In order to its being breathed, it is first passed into an oiled silk bag, or into a bladder, in the way you have witnessed (p. 133). A tube attached to the bag is held in the mouth, and through this the gas is breathed from and into it. I have frequently witnessed its effects. Sometimes it produces the most extatic pleasure; which is evinced by leaping, dancing, shout-

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24. What besides this gas is produced in its decomposition?
25. How is the fact of this production of water explained?
26. What is the atomic composition of nitrate of ammonia?
27. By what new combination of these are water and nitrous oxide produced?
28. In what way does this gas operate upon burning bodies?

ing, and the performance of antic gestures of almost every kind. Those under its influence frequently manifest uncommon strength, and if resisted fight with great fury. In some persons it totally destroys the muscular powers, and even induces fainting. In fact, its effects are extremely discordant, and though curious, are upon the whole, rather painful to witness(29).

Caroline. Its influence very soon passes off, does it not?

Mrs B Yes, generally in the course of two or three minutes, but many experience a degree of elasticity and cheerfulness for hours after its direct effect has ceased. I have never known, or heard, of any permanently bad effect from it, but as there is no advantage to result, I think it best not to try it(30).

Caroline. I, for one, have no inclination to get scientifically tipsy, as I well know, that when in my sober senses, my sayings and doings partake sufficiently of the extravagant; and I should expect, under the influence of your leaping, dancing and shouting gas, to exhibit the very perfection of the ridiculous.

Mrs B. At the commencement of our last conversation I gave you a table of the combining atoms in the five compounds which we have since considered, and will now present the same to you, with some additions, in order that you may investigate it at your leisure. In the former table you had the number of combining atoms only; the additions in the present consist of the atomic weights of the oxygen and nitrogen, and of the numbers which represent the weight of an atom of each of the compounds.

Compounds.	*Atoms of Nitrogen.*	*Atomic weight*	*Atoms of oxygen.*	*Atomic weight.*	*Wt. of atom of compound.*
1. Nitrous oxide	1	14	1	8	22
2. Nitric oxide	1	14	2	16	30
3. Hyponitrous acid	1	14	3	24	38
4. Nitrous acid	1	14	4	32	46
5. Nitric acid	1	14	5	40	54

Caroline. I plainly perceive the use of this table. It shows that as an atom of nitrogen is represented by the number fourteen, and an atom of oxygen by the number eight, if one of each of these combine, an atom of the compound must weigh twenty-two; whilst if the atom of nitrogen combines with two atoms of oxygen, the weight of the compound atom will be thirty; as to the twenty-two must be added the eight which represents the additional atom of oxygen: and so of the other compounds(31).

Mrs B. I am gratified at your ready comprehension of the use of this table. It is the practice now to employ numbers upon this principle, in order to represent all the compounds, the constitution of which are known. The numbers usually employed relate to hydrogen, the atomic weight of which being considered as unity. Thus, as you will recollect, an atom of nitrogen is fourteen times as heavy as one of hydrogen; an atom of oxygen eight times as heavy; and therefore an atom of nitric acid, which consists of one of nitrogen and five of oxygen, must be fifty-four times as heavy. Such numbers are called *equivalents*, and tables of them accompany all the modern treatises on chemistry(32).

Emily. Such tables must be not only very useful, but I should suppose absolutely necessary, as it would be scarcely possible to treasure in the

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29. What is said of the respiration of nitrous oxide?
30. Is its effect upon the system of long continuance?
31. What does the above table show respecting these compounds?
32. What further is said on the subject of atomic weights?

memory all the numbers which represent the atomic weights, even of the simple substances alone.

Mrs B. We have already noticed some of the salts produced by the union of nitric acid with different bases, but there is one of them which is of such special importance, both in chemistry and the arts, as to demand a more particular examination than either of the others. I allude to the *nitrate of potassa.*

NITRATE OF POTASSA, called also NITRE or SALT-PETRE, was known to the Romans. But the earliest account which we have of it is derived from the annals of the Chinese, who appear to have been acquainted with it from remote antiquity. This is the less remarkable, as it is a natural product, and is found in many situations(33). In Italy, Spain, India, China, Persia, and some other countries, it is contained in the soil in such large quantities, that the greater part of what is used in Europe and in this country is supplied from those sources.

Caroline. And has it not been found in the United States also? I certainly think that I have read some accounts of nitre caves in Virginia, Kentucky, and elsewhere.

Mrs B. You are correct on this point. There are many nitre caves, as they are called, from the contents of which much nitre has been manufactured; and when the country in their vicinity becomes more populous, these caves may be of great value(34). They contain a portion of nitrate of potassa, but the predominant substance is *nitrate of lime*, which, to be converted into nitre, must be decomposed by means of carbonate of potassa. By a recurrence to what you have learnt respecting double elective attraction, (p. 208;) you will readily understand this process. The nitrate of lime, and the carbonate of potash, are both soluble in water, and they can, therefore, be mixed intimately together(35).

Emily. And there can be no difficulty in tracing their action upon each other. The nitric acid will displace the carbonic acid from the potash, and, uniting with it, will form nitrate of potash; whilst the carbonic acid will combine with the lime, and convert it into a carbonate. But how can these two new compounds be separated?

Mrs B. They separate themselves. The nitrate of potassa remains in solution, whilst the carbonate of lime, being insoluble, is precipitated. The nitre is afterwards obtained in crystals by evaporating the water(36).

The sweepings from the streets of cities, mixed with the mortar and other rubbish from old buildings; the cleanings of cellars, and the earth from the places where cattle are numerous, if placed in heaps, and exposed for some weeks to the action of the atmosphere, will, by this means, be made to afford nitrate of lime and of potassa. Nearly the whole of the nitre used in France during the wars of her revolution was obtained from such sources(37).

Caroline. Nitre, I know, is a very combustible substance, as I have often thrown pieces of it into the fire to see the brilliancy with which it would burn. This, however, I do not understand, as it is composed of nitric acid and potash, neither of which is combustible alone(38).

Mrs B. Nor are they so when in combination; when you have thrown nitre into the fire, you have allowed your senses to deceive you. The nitre

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33. What is observed respecting the natural production of *nitre?*
34. From what places has it been principally obtained?
35. What is observed of the nitre caves of the United States?
36. How is *nitrate of lime* converted into nitrate of potassa?
37. How may nitre be artificially produced?
38. What does Caroline observe respecting the combustion of nitre?

merely imparted oxygen to the coals, and caused them to burn brilliantly. Had you thrown your nitre upon a brick or stone, heated to redness, there would not have been any appearance of combustion(39).

Caroline. I plainly perceive my error, now you have pointed to its source. There was no fact, however, which I considered as more completely established than that of the combustibility of nitre.

Mrs B. Your mistake was a very natural, and a very common one; as the appearance to which you alluded seems fully to justify the inference drawn from it.

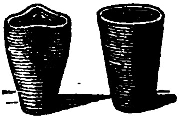
Nitre, when brought to a low red heat, is decomposed, affording, in the first instance, a large quantity of oxygen gas, sufficiently pure for all the ordinary experiments of the laboratory, or of the lecture room. To obtain the gas from this salt, a portion of it is put into a retort of iron or of earthenware, to which a long tube is attached, in order to conduct the oxygen into a receiver; the retort is placed in a fire, and as soon as it becomes red-hot, the extrication of the gas commences. One pound of nitre will yield about seven gallons of oxygen. If, however, the process be continued too long, or the heat be too great, a portion of nitrogen will accompany the oxygen, and at length nitrogen nearly pure will pass over, and the process be defeated(40).

Emily. I am not surprised that oxygen and nitrogen are both extricated from nitre, as the nitric acid is so readily decomposed by heat; but why they should not be mixed together during the whole process I do not comprehend.

Mrs B. During the first period of the decomposition, oxygen alone is obtained, because the *nitric* is merely reduced to the state of *nitrous acid*, whilst this last is retained by the attraction of the potash, forming with it a *nitrite of potash;* but if the decomposition be pushed further, this nitrous acid will also be decomposed, and nitric oxide and nitrogen gases will be obtained instead of oxygen(41).

You now understand that the reason why nitre promotes combustion, is the facility with which it parts with its oxygen. The metals are sometimes oxidized by what is called DEFLAGRATION. That is, by mixing them with nitre, and projecting the mixture into a red hot crucible. The nitre is thus made to yield its oxygen to the metal(42).

Earthen Crucibles.



Caroline. Crucibles, I believe, are earthen vessels in which metals are melted, and other substances heated in the fire.

Mrs B. The chemist sometimes uses crucicles of platinum, or of silver. But for most purposes they are made of earthenware(43). I have two of these latter now in the fire, and heated to redness. In one of them I will show you the *deflagration of charcoal,* and that of *sulphur* in the other. For this purpose I have pulverized portions of each of these substances, and mixed them separately with nitre. Into this crucible I throw some of the mixture of sulphur and nitre.

Emily. That is really a rapid and beautiful combustion. The sulphur burns more splendidly than it did in oxygen gas, in your experiment some time ago. It is well that the vapour passes up the chimney, for even now it gives out a strong smell of sulphurous acid.

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39. What appears to be the fact upon this subject?
40. In what way may oxygen gas be obtained from nitre?
41. What further remarks are made on the decomposition of this salt?
42. What is *deflagration,* and how is it effected?
43. What are *crucibles?*

Mrs B. Both sulphurous and sulphuric acids are produced in this process, and a portion of the latter combines with the potash of the nitre, forming a sulphate of potash, which will remain in the crucible; sulphurous acid and nitrogen passing off in the gaseous state(44).

I will now deflagrate the charcoal in the other crucible.

Caroline. It burns almost like gunpowder, only more slowly.

Mrs B. If we had mixed the three together, that is, the charcoal, sulphur and nitre, they would have burnt exactly like gunpowder, for such they would actually have been(45). And instead of a *deflagration*, we should have had a DETONATION; that is a combustion so rapid as to produce an explosion accompanied with a loud report(46).

Gunpowder is made by combining together, very intimately, six parts of nitre, one of charcoal, and one of sulphur, and you are aware of the rapidity with which this mixture burns, and of the immense force with which it explodes(47).

Emily. And how is this violent detonation of gunpowder accounted for?

Mrs B. When we deflagrated the sulphur, sulphurous acid and nitrogen gases escaped, and from the deflagrated charcoal carbonic acid was produced, which was also accompanied by the nitrogen of the decomposed nitric acid. With the exception of the potash, nearly the whole of the solid powder, therefore, suddenly assumes the gaseous form. This gaseous matter, from its quantity and from its expansion by the high degree of heat produced by the combustion, operates with a force about one thousand times greater than that of the atmosphere. And it is this expansion which produces the detonation(48).

Caroline. The heat accompanying this and similar explosions occasioned by the rapid formation of gaseous matter, you adduced as one of the objections against the Lavoisierian theory of combustion, and it certainly is a valid one, as according to that theory, the sudden formation of gaseous matter by the dilatation of solids ought to produce cold. Yet in this case and many others, heat is disengaged(49).

Mrs B. An explosive mixture called *pulvis fulminans*, or *fulminating powder*, is made by mixing together in a mortar, *three parts of nitre, two of pearl ashes* (carbonate of potash), and *one of sulphur.* A few grains of this powder placed in a spoon and held over a lamp until it melts, will explode with a very loud report. This explosion, like that of gunpowder, is occasioned by the sudden formation of gases(50).

Nitre is one of the most useful of the saline compounds. Its greatest consumption is in the manufacture of gunpowder; but it is employed for many purposes in the laboratory of the chemist, to whom it affords oxygen, and nitric acid, and aids in the formation of sulphuric acid. The refiner of metals uses it in his operations; the physician administers it in small doses to allay fever, and by fumigating infected places by the vapour of nitrous acid, disengaged from this salt, it is said that the matter of contagion has been destroyed. Its application to the salting of meat is familiarly known(51).

Emily. I am apprehensive that after nitrate of potash, the other salts of this class will appear comparatively insignificant.

Mrs B. Some of them, such as the nitrate of silver, and the nitrates of some other metals, have been already noticed. The nitrate of lime is prin-

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44. What is formed by the deflagration of sulphur?
45. Of what ingredients does gunpowder consist?
46. What is meant by *detonation?*
47. In what proportions are the ingredients of gunpowder mixed?
48. How is the violent detonation of gunpowder accounted for?
49. Does the Lavoisierian theory of combustion explain this phenomenon?
50. How is fulminating powder formed?
51. Detail some of the uses to which nitre is applied.

cipally valuable as affording nitre. The nitrate of ammonia you have seen produced, and decomposed for the purpose of making nitrous oxide. Nitrate of soda is in many respects similar to nitre; but in utility it is very inferior to it. The nitrates possess one property in common; that is, the facility with which they afford oxygen to most combustibles. They have hence been classed by some chemists among what they have denominated *compound supporters of combustion*(52). With the exhibition of an experiment by means of *nitrate of copper* and tin foil, I shall dismiss this class of bodies.

Caroline. This green salt, labelled *nitrate of copper*, you obtained, I believe, by evaporating the liquid nitrate which was formed when you procured the nitric oxide, or nitrous air.

Mrs B. It is the same. I take some of this crystallized nitrate, dry and in powder, and wrap it up in a piece of tin foil. The two materials will not, under these circumstances, act sensibly upon each other. I now take another piece of foil, and a quantity of the pulverized nitrate as before. Upon this I sprinkle a few drops of water, and quickly wrap it up in the foil, just as I did in the former case.

Emily. It has burnt, and actually emits sparks of fire, whilst that which was dry still remains unchanged(53).

Mrs B. The water serves to dissolve a portion of the nitrate of copper, and thus to bring it into close contact with the tin. This metal having a strong affinity for oxygen, decomposes the nitric acid of the nitrate of copper, and combines with its oxygen with such rapidity as to undergo combustion(54).

When we next meet, several different subjects will engage our attention: muriatic acid and chlorine, however, will be the principal.

CONVERSATION XXIII.

ON CYANOGEN, SELENIUM, BORON, FLUORIC ACID, MURIATIC ACID, AND CHLORINE.

Cyanogen, or Bicarburet of Nitrogen. Hydrocyanic, or Prussic Acid. Hydrogen, an acidifying principle. Hydracids. Prussian Blue. Prussic Acid in Vegetables. Cyanic Acid. Selenium. Boracic Acid. Borate of Soda, or Borax. Boron. Fluoric Acid. Fluate of Lime, or Derbyshire Spar. Silex and Glass dissolved by Fluoric acid. Etching upon Glass. Fluo-silicic Acid Gas. Fluorine, the unknown Base of Fluoric Acid. Muriatic Acid, or Spirit of Sea Salt. First procured in its Gaseous Form by Priestley. Obtained from Muriate of Soda. Description of Woulfe's Apparatus. Oxy-muriatic Acid, or Chlorine. Combustion of Metals, and of Phosphorus in this Gas. Its Bleaching Properties. Theory of its production. Two Theories respecting its Nature. Proofs that it does not contain Oxygen. Effect of Light upon a Mixture of Gaseous Chlorine and Hydrogen. Common mode of obtaining Chlorine.

Mrs B. In our last conversation, we have seen nitrogen, when in combination with oxygen, exhibiting very active properties. You had previously witnessed a similar fact, when examining the volatile alkali, in which nitro-

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52. What is observed respecting the nitrates generally?
53. Describe the experiment with nitrate of copper and tin foil?
54. What appears to be the agency of the water in this case?

gen united with hydrogen became a chemical agent of great power. I am now about to introduce it to you under a new character, resulting from its alliance to carbon, with which it forms a gas, sometimes called the *bicarburet of nitrogen*, but more generally denominated CYANOGEN. The first name may serve to indicate its composition, the last, one of its particular properties, as it is derived from two Greek words, signifying *blue*, and *to produce*; cyanogen producing a blue colour by its combination with oxide of iron, as is seen in that beautiful pigment Prussian blue(1).

Caroline. This paint then is a compound of oxide of iron, nitrogen, and carbon. I should never have supposed that it was so complex an article.

Mrs B. It is more complex than you even yet suppose; as the cyanogen, before it combines with the oxide of iron, is itself converted into an acid, called HYDROCYANIC, or PRUSSIC ACID. This acid claims your particular attention, as hydrogen is its acidifying principle(2). There are several other acids in which hydrogen performs the office once supposed to belong exclusively to oxygen. This was intimated when speaking of *sulphuretted hydrogen* (p. 141). Acids of this kind are called *hydracids*. The name *hydrocyanic*, applied to prussic acid, serves to point it out as a compound of hydrogen and cyanogen(3).

Emily. The name *prussic acid* is evidently derived from that of the colour which contains it. And although not so systematic as *hydrocyanic*, it seems to be more convenient, as showing its origin.

Mrs B. Both names are used, and I shall employ them indiscriminately, that they may become equally familiar to you(4).

To obtain *cyanogen*, a *prussiate of mercury* is formed by boiling Prussian blue (*hydrocyanate of iron*) with red oxide of mercury; the prussiate of mercury thus formed is decomposed by heat, and affords cyanogen. It is a colourless gas of a very pungent odour, and, like hydrogen, extinguishes burning bodies, whilst it is itself inflammable(5). When combined with hydrogen, under the form of prussic acid, it furnishes one of the most active and virulent poisons with which we are acquainted. A single drop of it placed on the tongue of a large dog caused his death in the course of a few seconds. The vapour which rises from it, and mixes with the atmosphere during its preparation, produces headach, giddiness, and fainting(6).

Caroline. I shall take good care to avoid the contact of so dangerous a compound; and shall almost fear to paint again with Prussian blue.

Mrs B. Your fear will be groundless, and your caution unavailing. In Prussian blue the acid is disarmed of its terrors by its combination with iron. But it exists in a free state in the *liqueur* called *noyeau*, the peculiar odour and flavour of which are produced by it. Bitter almonds, and the kernels of peaches, cherries, and other fruits contain it. You are not likely therefore always to avoid contact with it, or if you do, you must not only be very cautious but very self-denying. The extremely poisonous water distilled from the cherry laurel (*prunus lauro-cerasus*) derives its qualities from the large quantity of this acid which it contains. Prussic acid has been introduced into medicine; and you are aware that such is the case with other active poisons, and that they hold a place among the most valuable of our remedies(7).

Emily. Are there many important salts formed by the hydrocyanic acid?

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1. Of what is *cyanogen* composed, and what does it form with oxide of iron?
2. What is *prussic acid*, and how is it formed?
3. What is remarked respecting some analogous acids?
4. What is observed respecting the two names of prussic acid?
5. From what is *cyanogen* obtained, and in what form does it exist?
6. What is said of *hydrocyanic*, or prussic acid, as a poison?
7. Of what vegetables does it form a component part?

Mrs B. The *ferrocyanate* or *prussiate of iron* is the principal. Combined with potash, it forms *prussiate of potash*, which is used as a test of the presence of iron, to the solutions of which it imparts a fine blue colour. Cyanogen forms an acid, not only by its combination with hydrogen, but also by combining with oxygen. This latter is called *cyanic acid*, but its properties, or those of its combinations, do not require our notice(8). I shall therefore dismiss cyanogen, and direct your attention for a few minutes to a substance called *selenium*.

Emily. This, I believe, is as new to us as cyanogen. I do not recollect that we have ever heard you name it until now.

Mrs B. SELENIUM is a peculiar substance, apparently simple, which has been discovered, in company with sulphur, in some sulphurets of iron, and in a few other combinations. The quantity of it which has been obtained is very small. Its appearance is somewhat metallic, and from this cause it was at first classed with the metals; but it is now considered as more nearly allied to sulphur(9). It is combustible, although it burns with difficulty. Its vapour has a very peculiar odour, resembling that of decayed horse-radish It combines with oxygen in three proportions, forming *oxide of selenium*, and *selenious* and *selenic acids*(10). We know but little more respecting it, and shall therefore pass on to other matters.

Caroline. I am at a loss to perceive what useful purpose can be answered in the economy of nature by substances so sparingly diffused as selenium, yttria, and some others.

Mrs B. This is a point upon which your curiosity is likely to remain unsatisfied, as those who are wiser than we can pretend to be, are obliged, on this subject, to rest satisfied with the assurance, that the Being who created these materials, acted, in their creation, under the guidance of that wisdom which is distinctly manifested in all his works, so far as human power can investigate them.

Emily. The phial from which you have just poured these shining crystalline scales is labelled BORACIC ACID; this differs essentially from most of the acids that we have lately seen.

Caroline. After such articles as sulphuric, nitric, and especially prussic acid, to which we have been lately introduced, I am glad to meet with one that we need not fear to touch, and which appears to be perfectly innocent.

Mrs B. BORACIC ACID is obtained from a salt usually called *borax*, the *borate of soda* of the chemists(11). The borate of soda is used in soldering, in refining metals, and in some other processes in the arts. This native alkaline salt is found in large quantities in the East Indies, where there are several lakes in the bottoms of which it is constantly deposited; and it is now procured in considerable quantities in Tuscany. In the impure state in which it is imported, it is called *tincal;* but that which you see in this other phial is refined borax(12).

Emily. This salt must, of course, be decomposed in order to separate the soda from it, and thus to furnish the boracic acid?

Mrs B. Yes; and the decomposition is very readily effected in consequence of the boracic acid being but sparingly soluble in water. The borate of soda is first dissolved in this fluid, and to the solution is added sulphuric acid, which combines with the soda, forming sulphate of soda (Glauber's salt.) The boracic acid, from its insolubility, is precipitated in shining

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8. What is said of its salts, and of *cyanic acid?*
9. What information is given respecting *selenium?*
10. What are its properties and combinations?
11. What is the appearance of *boracic acid*, and from what is it obtained?
12. Where is borax procured, and to what uses is it applied?

scales, and these, after pouring off the solution, are washed with pure water, and then dried(13).

Caroline. But that, I suppose, is only a partial decomposition, as this acid, like its relatives, must also be a compound.

Mrs B. It had long resisted every attempt to decompose it, but at length Sir Humphry Davy succeeded in effecting its decomposition, by subjecting it to the action of his powerful voltaic battery: by this means he obtained from it its base, which is denominated BORON. This is an olive coloured substance, which appears to be as insoluble and as inactive as charcoal(14). On heating it in oxygen gas, it burns with considerable brilliancy, and is reconverted into boracic acid. One characteristic of this acid is its solubility in alcohol, and its imparting to that liquid the property of burning with a beautiful green flame; as you will see by that which I inflame in this spoon.

Emily. The colour is certainly beautiful, and quite peculiar. This combustion must offer an easy mode of distinguishing this acid(15).

Mrs B. Boracic acid is but sparingly employed in medicine or the arts, and its combinations, excepting that in which it is found in nature, offer nothing of importance. I shall therefore proceed to the examination of the *fluoric acid*, and some of its salts.

FLUORIC ACID you will find to be a substance of much greater interest than those which we have last examined. The beautiful vases which stand as ornaments upon the mantle contain this acid; the substance of which they are formed being the FLUATE OF LIME.

Caroline. I have always heard this kind of stone called *Derbyshire spar*, and recollect well the account of the mines in which it is found, and the manner of working it into various ornaments. This spar is not obtained, I believe, in any other place excepting Derbyshire in England(16)?

Mrs B. Yes; it is found in almost every country, and sometimes in large masses, though most commonly in thin veins, or small pieces. It is, however, only in the place you mention, that it is met with of a texture which admits of its being wrought into ornaments. This mineral is often called *fluor spar*, a name which it derived from its fusibility, and from its consequent use as a *flux* in the reduction of the ores of some metals. The acid which is obtained from it is, as I have already informed you, called the fluoric acid(17).

Emily. And what are the peculiar properties which render this acid an object of particular interest?

Mrs B. Have you forgotten my allusion to it, when speaking upon the subject of silex? This acid readily dissolves flint and all the other siliceous minerals, and therefore cannot be obtained, or kept, in glass vessels; the silex and alkali of which glass consists yielding rapidly to its solvent power. Lead is but slightly, and silver not at all, affected by it; and therefore, one or other of these metals is used in the procuring of, and in experimenting with the acid(18).

Fluoric acid is obtained by pouring sulphuric acid upon the fluor spar. The sulphuric acid combines with the lime of the spar, converting it into a sulphate, whilst the fluoric acid, which is a very volatile liquid, distils over, and is condensed in a vessel surrounded by ice(19). Whether in the

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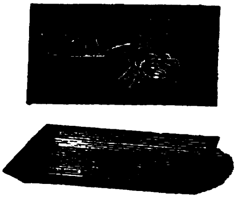
13. By what process is the boracic acid separated from borax?
14. What is the base of this acid called, and what is its appearance?
15. What particular properties of boracic acid are mentioned?
16. In what mineral is *fluoric acid* contained?
17. What is said of the names and the localities of this mineral?
18. What are the distinguishing properties of fluoric acid?
19. How is it separated from its combination with lime?

liquid form, or in that of vapour, it is, next to prussic acid, the most corrosive and deleterious of all this class of bodies. The vapour which escapes from it excites violent fever, and produces long continued and intense suffering. A drop of the liquid coming in contact with the skin will form a deep seated and obstinate ulcer. A dog, upon whose back six drops of it had been allowed to fall, suffered extreme agony, and died in the space of a few hours(20).

Caroline. I shudder at the very idea of such a compound, and have no inclination to disturb it in its quiet possession of the lime in the fluor spar.

Mrs B. We can, with perfect safety, obtain enough of it to enable us to examine its effects in dissolving, or corroding, glass. Pictures are sometimes etched upon pieces of glass by means of the liquid acid. A similar effect, however, may be produced, though less perfectly, by very simple means. I have prepared this small pane of glass for etching, by making it warm and then rubbing bees-wax upon it, so as to coat it completely over on both sides. By means of a sharp point, I have, on one side, drawn a flower through the wax coating, taking care that the point should penetrate to the glass. If I now expose that side to the vapour of fluoric acid, the part covered with wax will be defended from its action, whilst those which the point has made bare will be engraved, or rather etched, having lines distinctly excavated in the glass.

Glass and trough for etching with Fluoric Acid.



Emily. And how will you manage to apply the vapour?

Mrs B. I have a tray made of lead, somewhat smaller than the glass to be etched; into this I put a portion of the spar, in powder, and pour on it sulphuric acid enough to moisten it. This tray I now cover with the glass, placing the drawing downwards. The fluoric acid, in vapour, will rise from the spar, and act upon the glass. To accelerate the operation, the tray may be heated, but, of course, not sufficiently to melt the wax. The etching may require half an hour for its completion. Instead of the leaden tray, I have sometimes used a common saucer coated with bees-wax, which serves to protect it from the acid(21).

Caroline. The compound formed by the union of the fluoric acid with the silex must be a fluate of silica, that is, if it is accounted a saline body.

Mrs B. Instead of forming a salt, it still appears to possess the properties of an acid; and, what is very remarkable, as it forms this combination, it passes into the gaseous form. The liquid fluoric acid unites with solid silex, and this union produces an elastic fluid, which is called *fluo-silicic acid gas*(22).

Caroline. No wonder that stones fall from the atmosphere, when flint can be converted into thin air! This is certainly one of the most extraordinary of the gases.

Mrs B. Whilst kept from moisture, this gas is a permanently elastic fluid, but water absorbs it with very great rapidity. When this absorption takes place, the gas deposits about one-third of the silex which it contained. This gives rise to a very curious phenomenon. As the separation takes place on the passage of the gas into the water, the silex is deposited upon its surface, where it forms an incrustation resembling a thin pane of glass,

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20. Relate what is said respecting its corrosive properties?
21. How may glass be etched by means of this acid?
22. What combination does fluoric acid form with silica?

which, unless it is broken, arrests the further absorption of the gas. Any moist substance, if exposed to an atmosphere of this gas, will acquire an incrustation of silex; a sprig of any vegetable, or a small animal, may thus be made to assume the appearance of a petrifaction(23).

Emily. You have not informed us, Mrs B., respecting the composition of the fluoric acid itself: has it been decomposed?

Mrs B. The name *Fluorine* has been given to the supposed base of this acid. But although the most able chemists have been engaged in the attempt to discover its composition, it has hitherto resisted their efforts. It is believed by many to be one of the *hydracids*, having a peculiar unknown base, acidified by its combination with hydrogen. In conformity with this opinion, it is sometimes called *hydro-fluoric acid*(24).

Caroline. May there not be such a thing as a simple acid? If so, the endeavours of the chemist to decompose it must, of course, be altogether in vain.

Mrs B. The existence of such an acid is, undoubtedly, possible; but where we have not been able to arrive at certainty in our conclusions, we must adopt as our guides those high probabilities which are the result of our reasoning upon analogous facts; and strong analogy will not permit us to doubt that the fluoric, like all the other known acids, is a compound. A few years since, there were three acids classed together as undecomposed bodies; the *boracic*, the *fluoric*, and the *muriatic*. The first, the boracic, has been decomposed, so as to leave no doubt of its nature; the second, the fluoric, has not yet yielded to the efforts of the chemist; the third, the muriatic, is now admitted into the class of hydracids as a compound of chlorine and hydrogen(25). It is to the properties of the latter acid and to its base that I shall now direct your attention; and it is my design to treat this subject by the analytical method; first explaining to you the properties of the acid, and afterwards inquiring into its composition.

Emily. This seems to be a very natural mode of proceeding, as it is that in which the chemist must acquire his knowledge in the first instance; for nature presents but very few substances to him in their simple or elementary form, but furnishes compounds which he is compelled to analyze.

Mrs B. MURIATIC ACID is found in nature combined with lime, magnesia, and soda; but most abundantly with the last. The common salt of our tables is the *muriate of soda*(26), and from this the liquid muriatic acid is disengaged by the agency of sulphuric acid. Glauber, a Dutch chemist of the sixteenth century, was the first who obtained it by this process; and from his name, the sulphate of soda, which remains in the retort after the muriatic acid is driven off, was called Glauber's salt(27).

As the sea is the great source of the muriate of soda, the acid obtained from it was called the muriatic, from *muria*, the Latin name of sea salt. It is also called the *marine acid*, and the *spirit of sea salt*(28). Although the muriatic acid had been long known, it was first obtained in a state of purity by Dr Priestley, who discovered that it was a permanent gas. In this form it is extremely suffocating and corrosive, very rapidly destroying the life of an animal confined in it. The liquid acid, some of which I have in this bottle, consists of muriatic acid gas, absorbed and condensed by water, one pint of which will take up between four and five hundred pints of the gas(29).

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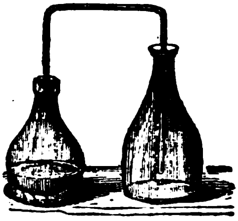
23. What remarkable properties does the *flue-silicic acid* possess?
24. What is said respecting the composition of fluoric acid?
25. Why are we justified in concluding that it is a compound?
26. In what combination is *muriatic acid* found most abundantly?
27. Who was its discoverer, and by what means did he obtain it?
28. What is said respecting the names given to it?
29. What is the form, and what the properties of the pure acid?

Caroline. Then we cannot collect this gas by means of the pneumatic cistern, as the water would absorb it as fast as it was produced.

Collecting gaseous Muriatic Acid.



[A. Flask containing muriate of soda and sulphuric acid.]

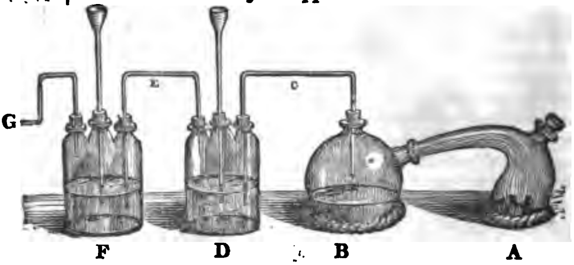
Mrs B. A mercurial trough, or cistern, is used for that purpose; but as the specific gravity of the gas exceeds that of atmospheric air, it can be collected in a bottle, as we formerly collected carbonic acid (p. 157)(30); it is necessary, however, carefully to avoid the fumes. I have now filled this bottle, and will invert it, placing the mouth of it in water.

Emily. How rapidly the water ascends and fills the bottle. I expected to see the gas absorbed, but not so suddenly. I observe that whenever this gas comes in contact with the atmosphere, a white cloud is formed, although the gas itself is colourless and invisible. This, I suppose, arises from its combining with the watery vapour which it finds in the air.

Mrs B. Certainly; and from the extreme eagerness with which this gas unites with water, so much heat will be set free, as to melt a portion of ice or snow, placed in it, as rapidly as though it were thrown into a fire(31).

An apparatus, called *Woulfe's apparatus*, is advantageously used in preparing the liquid acid. It is employed, in fact, in all those processes where liquids are to be impregnated by gases, and you ought therefore to understand its operation. This apparatus is made in various forms, but that which I have on the table is the most common. The bottles, you perceive, are furnished with three necks, and they contain a portion of water, which is to be impregnated with the gas.

Woulfe's Apparatus.



When muriatic acid is to be formed, common salt is put into the retort [A], and sulphuric acid, a little diluted, poured upon it. On applying heat to the retort, the gaseous muriatic acid passes into the globe [B]; and in that is deposited any condensible vapour which would render the acid impure. From this globe the gas passes through the bent tube [C], which should terminate above the surface of the water in the first bottle [D]. This water absorbs a portion of the gas, and the remainder passes through the tube [E], which dips below the water in the next bottle [F]. In this way any number of bottles may be connected together, and the process continued until the water in each is completely saturated. To promote the

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30. By what methods may this gaseous acid be collected?
31. What occurs when it comes in contact with water, with air, or with ice?

absorption of the gas, the bottles may be surrounded with ice. Any atmospheric air, or other gas, which the water will not absorb, may be allowed to escape at the tube [G] in the last bottle.

Caroline. You have explained the use of the bent tubes, but not of the straight ones which pass up from the middle neck.

Mrs B. These tubes, called safety tubes, are intended to admit atmospheric air into the bottles, when its admission may become necessary. As, for instance, when, from diminished action in the retort, the gas ceases to come over. A vacuum may then be produced in the globe [B], as the water in the first bottle [D] will be likely to absorb the portion of gas which it contained. The pressure of the atmosphere, acting through the tubes [G,E and C] would then cause the fluid in the first bottle to pass over into the globe, and it would be spoiled by mixing with the impurities which the globe had detained. The central tubes prevent this from taking place; for, the air of the atmosphere will rush in through them, and bubble up through the fluid into which they dip, whenever a vacuum is formed in either of the bottles(32).

In using this apparatus all the tubes must be made to fit air tight. In the manufactories where muriatic acid is made upon a large scale, vessels of iron, and of earthenware, are used, instead of those of glass. A little iron is usually contained in the acid of commerce, and from this cause it assumes a yellow colour(33).

Caroline. As this acid contains a substance with which we are at present unacquainted, I feel a good deal of interest upon the subject of its decomposition.

Mrs B. And to gratify you in this particular, I will omit all further notice of the muriates, until you have obtained some information respecting *chlorine.*

Chlorine was discovered by the eminent Swedish chemist Scheele, and the process by which he obtained it is still pursued. Strong muriatic acid is mixed, in a retort, with about half its weight of the *peroxide* (black oxide) *of manganese:* chlorine gas will immediately begin to escape, and may be collected over the pneumatic cistern, provided the water in it be heated to eighty or ninety degrees of Fahrenheit's scale. This is necessary, as water at a lower temperature absorbs a portion of the gas, and if quite cold, will take up its own volume; which it will give out again when heated. As chlorine is much heavier than atmospheric air, it may, like muriatic acid gas, be collected in bottles standing upright, which, when filled, should be closed by well ground stoppers. The fumes that arise from chlorine should be carefully avoided, as they are not merely unpleasant, but deleterious(34).

Emily. So far it appears to resemble the muriatic acid itself, from which it is obtained.

Mrs B. You will find however that it is a very different substance, and that in its chemical relationships it bears a strong affinity to oxygen; being, like it, a supporter of combustion, converting some combustibles into *chlorides,* a class of compounds which are analogous to oxides, and combining with others of them in such proportions as to produce acids(35).

We have now a sufficient quantity of chlorine collected to show its properties, some of which are very peculiar.

Caroline. It already exhibits one peculiarity, as, unlike all the other

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32. Describe the construction and the use of Woulfe's apparatus.

33. From what cause does the muriatic acid of commerce appear yellow?

34. Who was the discoverer of *chlorine,* and by what method and under what precautions may it be obtained?

35. What is said respecting its analogy with oxygen?

gases which you have prepared, it is coloured, the bottles which contain it assuming a greenish-yellow appearance.

Mrs B. It was this character that suggested to Davy the name by which it is now called; the term chlorine being derived from a Greek word signifying green. It had been previously called *oxygenized* or *oxy-muriatic acid*, the reason of which will hereafter appear(36).

I have said that this gas is a supporter of combustion, and in fact, with the exception of carbon, all combustibles burn in it. Many of them will take fire spontaneously, when placed in a vessel containing it, without requiring to have their temperatures previously elevated(37).

Emily. Are not the thin metallic leaves which you are taking up called Dutch metal, or Dutch gold leaf?

Mrs B. They are. And I will now immerse one of them in a jar of the chlorine, and you see that it immediately takes fire.

Emily. Yes, indeed it did, and the combustion too was very rapid. I suppose a chloride has been formed; but a chloride of what?

Mrs B. This Dutch metal consists principally of copper, and of course its chloride is the main product. Other metals in thin leaves burn in the same way. In their combustion they also are converted into chlorides. I will next drop some antimony, and then some zinc, in fine filings, into separate portions of the gas, and each of them will inflame and burn with great brilliancy(38).

Caroline. They form a complete shower of fire, and were it not for the excessively disagreeable smell of the gas, the experiment would be altogether a most pleasing one.

Mrs B. We will try the same experiment with the piece of phosphorus which I have in this copper ladle. You had better stand on this side, that when I open the jar the wind may blow the vapour from you.

Emily. It takes fire and burns beautifully, although by no means so splendidly as in oxygen gas(39).

Mrs B. These examples of combustion must suffice; as I wish now to show you the extraordinary power of chlorine in destroying colour; or in other words, its bleaching property. In one of these jars of the gas I will place a red rose, and in the other a piece of printed calico, and its influence will be very quickly seen.

Emily. The rose is already nearly white, and the calico is becoming so on its edges(40).

Mrs B. There are but few colours which resist this agent. And all those which are derived from animal or vegetable substances are completely discharged by it. This property of chlorine has been turned to good account in the manufacture of cotton and linen goods, of paper, and of many other articles which require to be bleached(41).

Caroline. I do not understand in what way the black oxide of manganese operates, in the conversion of muriatic acid into chlorine. This oxide, I know, has a tendency to part with oxygen, but I do not perceive how this can produce the decomposition in question.

Mrs B. You recollect the composition of muriatic acid?

Caroline. Certainly. You informed us that it consists of hydrogen and chlorine.

Mrs B. You will readily understand in what way the decomposition is

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36. Why is it named chlorine, and what was it formerly called?
37. What is remarked respecting its power of supporting combustion?
38. What experiments are detailed, and what is their result?
39. How will phosphorus be affected if placed in this gas?
40. What evidence is given of the bleaching power of chlorine?
41. To what use has it been applied in consequence of this property?

effected. The peroxide of manganese parts with a portion of its oxygen, which combines with the hydrogen of the muriatic acid, forming water. The acid is of course decomposed, and the chlorine set at liberty(42).

Such is the theory of its action; and without waiting to puzzle you with numbers, I will merely observe that when examined by the law of definite proportions, it is in perfect accordance therewith. After the decomposition of the acid, and the disengagement of its chlorine, there remains in the retort a muriate of manganese; that salt being formed by the combination of a portion of the muriatic acid with the protoxide of manganese. The attraction of chlorine for hydrogen, and of muriatic acid for the protoxide of manganese is the cause of the decomposition(43).

Caroline. I am still thinking of the old name of chlorine, *oxymuriatic acid.* This name seems to point out a combination between muriatic acid and oxygen, which, if it took place, would account for the fact that many of the properties of oxygen are possessed by chlorine.

Mrs B. At the period of the adoption of this name, muriatic acid was believed to be an undecompounded substance, but capable of forming a combination with oxygen; and it was imagined that in the process by which chlorine is procured, oxygen was supplied to it by the oxide of manganese, and that whenever it parted with this oxygen it returned to the state of muriatic acid(44). A number of facts seemed to justify this opinion; I will mention one only. When chlorine (oxymuriatic acid) had been employed in bleaching, it was found that it eventually ceased to produce this effect, in consequence of its passing into the state of muriatic acid. As oxygen was known to be the agent upon whose influence the discharge of colours principally depends, it was a very natural conclusion, that the bleaching power of chlorine (oxymuriatic acid) resulted from the facility with which it was supposed to furnish oxygen in a nascent state, which, combining with the colouring matter, effected its removal(45).

Caroline. I am somewhat afraid of my own confidence; but it seems to me that the fact which you have stated, lends no feeble support to the old theory. How can chlorine give out oxygen, if it does not contain any?

Mrs B. If it takes hydrogen from water, oxygen is given out by its agency, although not from its own substance. Now in all those processes in which chlorine assumes the form of muriatic acid, water is present; and if by seizing upon its hydrogen the chlorine returns to the state of muriatic acid, the nascent oxygen of the water will produce all the effects which were formerly ascribed to it when it was supposed to be derived from the decomposition of oxymuriatic acid. Perfectly dry chlorine does not produce any change in coloured substances, but as soon as moisture is admitted, the bleaching operation commences(46).

Caroline. It seems very curious, however, that all the effects of chlorine should be so readily accounted for upon either theory; and I should think that it is a subject still worthy of examination.

Mrs B. There are some few facts which, when placed before you, may not appear to be so reconcilable with the idea of the compound nature of chlorine as that already stated. Three of these I will mention, and then dismiss the controverted point altogether; proceeding in all our subsequent explanations on the received opinion that chlorine is an elementary body.

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42. How does the oxide of manganese aid in decomposing muriatic acid?
43. What remains in the retort after the chlorine has escaped?
44. Chlorine was formerly called oxymuriatic acid, what was the reason for applying this name to it?
45. What fact was calculated to sustain this opinion?
46. How are the disengagement of oxygen and the production of muriatic acid now accounted for?

Caroline. I shall be obliged to you for these facts, and will promise you not to urge any more of my crude objections; but to be what I ought to be, a listener and a learner.

Mrs B. When equal measures of chlorine and of hydrogen gases (both perfectly freed from moisture) are mixed together, if an electric spark be passed through the mixture they instantaneously combine, heat and light are emitted, and muriatic acid is formed. The weight of the acid will be exactly equal to that of the two gases, and no oxygen will be obtained. Any other mode of igniting the gases will answer equally well(47).

If charcoal in a state of intense ignition be kept in chlorine, the gas suffers no change whatever. The charcoal does not acquire any oxygen, and as it will not burn in chlorine, no chemical effect whatever is produced.

Emily. That appears very remarkable, as ignited charcoal decomposes almost every oxide. If chlorine contained oxygen loosely combined, it certainly would give it up to the charcoal(48).

Mrs B. Again; if chlorine, perfectly dry, be exposed in a glass receiver to the action of light, no change whatever will be produced in it. But if any moisture be present, muriatic acid will be generated, and oxygen gas set at liberty. In the sunshine this change is effected very quickly; more slowly in a feeble light, and in the dark not at all. It is necessary, therefore, after we have obtained chlorine over water, to exclude the vessels containing it from the action of light, or it will soon be changed in its properties(49).

Caroline. These facts seem indeed to give a strong support to the elementary character of chlorine. The action of light in effecting the composition of muriatic acid is a circumstance which appears full of interest.

Mrs B. You have seen many instances of the chemical agency of light, and certainly its action on chlorine is not one of the least striking. The mixture of dry chlorine and hydrogen, which will ignite by the electric spark, will explode also the moment the direct solar ray is allowed to fall upon a glass vessel containing them, although in the diffused light of day their union is effected but slowly(50).

Emily. Does there appear to be any other compound of chlorine and hydrogen, excepting the muriatic acid?

Mrs B. No; and in this the combination is believed to consist of a single atom of each element. And as in muriatic acid the weight of the chlorine is thirty-six times that of the hydrogen, the equivalent number, or atomic weight, of chlorine will be thirty-six; and when to this we add one, the weight of an atom of hydrogen, we have thirty-seven as the equivalent of muriatic acid(51).

Before closing this conversation I will mention the process by which chlorine is obtained in the manufactories for the purpose of bleaching, as it differs from that by which we have procured it.

Three parts of common salt are mixed with one part of the peroxide of manganese in powder. This mixture is put into a retort, and two parts of sulphuric acid, diluted with an equal weight of water, are poured upon it. The sulphuric acid disengages the muriatic acid from the muriate of soda; the oxygen of the manganese combines with the hydrogen of a part of the

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47. How may muriatic acid be formed by the direct union of chlorine and hydrogen?
48. What is observed respecting charcoal ignited in chlorine?
49. What is remarked of the action of light upon chlorine?
50. What effect will it produce on a mixture of chlorine and hydrogen?
51. What are the atomic weights of chlorine and of muriatic acid?

muriatic acid, and reduces it to the state of chlorine, which passes off in the gaseous form. Can you tell me what will then remain in the retort(52)?

Caroline. I think I can; for although two operations are simultaneously performed, you have to-day explained them both to us. The sulphuric acid unites with the soda of the common salt, and forms a sulphate of soda, and whilst a part of the muriatic acid which is expelled from the soda is decomposed, in parting with its hydrogen to the oxygen of the manganese, another part combines with the protoxide of manganese, forming with it a muriate of that metal. The sulphate of soda and the muriate of manganese, in a state of mixture, must therefore be found in the retort(53).

Mrs B. I was apprehensive that the subject of our present conversation would have presented greater difficulties than you appear to have experienced in understanding it. By the combination of industry and method, you already have done much towards attaining a knowledge of some chemical changes which are among the most intricate that this science presents. Still, at our next meeting, you will find that the subject is not yet exhausted.

CONVERSATION XXIV.

ON THE COMPOUNDS OF CHLORINE, AND ON IODINE, BROMINE, AND THEIR COMPOUNDS.

Chlorides and Muriates. Hydrochloric Acid. Chlorine and Oxygen. Protoxide of Chlorine. Chloric and Perchloric Acids. Chloride of Nitrogen. Hydrocarburet of Chlorine. Chlorate, or Hyperoxymuriate of Potassa. Affords pure Oxygen. Match-lights. Combustion of Phosphorus under Water. Detonations with Sulphur, Phosphorus, and Metals. Percussion Powder. Muriate of Soda, or Chloride of Sodium. Sea Water. Sources and Uses of Common Salt. Muriate of Ammonia. Muriate of Lime. Chloride of Lime. Its Bleaching and Disinfecting Properties. Aqua Regia, or Nitro-muriatic Acid. Dissolution of Gold. Corrosive Sublimate, and Calomel. Iodine and Bromine. Their Properties and Combinations. Are Electro-negative Bodies. Uses of Iodine.

Caroline. It seems to me, Mrs B. that in operating with chlorine, it must sometimes be difficult to foretell whether you are about to form a chloride or a muriate. For as water is contained in the atmosphere, and in the gases generally, the chlorine may combine with the hydrogen of this water, and form muriatic acid, without our being aware of the change.

Mrs B. The difficulty which you have anticipated does actually exist. And there are cases in which chemists have not been able to determine, absolutely, to which of the two classes certain bodies belong. For a substance which is actually a chloride whilst it remains solid, may, when dissolved in water, obtain hydrogen, and thus become a muriate. I wish you to take special notice of this fact, and I shall shortly direct your attention to it more particularly in my remarks upon common salt(1).

Emily. There seems, in this case, to be some discrepancy in the names which you employ. That of muriatic acid certainly gives no indication of the elements of which this acid is compounded.

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52. How is chlorine usually obtained for bleaching?
53. What will remain in the retort after this process?
1. What difficulty may exist in tracing the operations of chlorine?

Mrs B. When the new nomenclature was adopted, the composition of this acid was unknown, and remained so for many years. The name muriatic acid had during this time become so familiar as to render a change both difficult and inconvenient. The French chemists call it *hydrochloric acid*, and its salts *hydrochlorates*; but as we continue to use the old name, you have only to charge your memory with the recollection of the composition of the acid, and all erroneous conclusions will be avoided(2).

I have told you that it is not with hydrogen alone that chlorine forms an acid, its union with oxygen producing a similar result. There are in fact four known compounds of oxygen and chlorine. These substances are all characterized by the feeble attraction of their constituents, very slight causes effecting their decomposition. Their names and composition are shown in this table(3).

Compounds of Chlorine and Oxygen.	*Chlorine.*	*Oxygen.*	*Atomic weight of compound.*
1. Protoxide of chlorine (*euchlorine*)	36, 1 at.	8, 1 atom	44
2. Peroxide of chlorine,	36, 1 at.	32, 4 atoms	68
3. Chloric acid,	36, 1 at.	40, 5 atoms	76
4. Perchloric acid,	36, 1 at.	56, 7 atoms	92(4).

Caroline: The large number of atoms of oxygen in some of these compounds, and the facility with which it is separated, must, I apprehend, cause them sometimes to act with great power, particularly upon combustibles.

Mrs B. You will find your conjecture fully verified; but as substances so easily decomposed cannot exist in nature, they are all under the control of the chemist, being his own artificial productions(5). The PROTOXIDE OF CHLORINE, sometimes called *euchlorine*, is a gas, the colour of which is similar to that of chlorine, but of a much deeper shade. It is extremely explosive; the warmth of the hand, or its agitation in pouring it from one vessel into another being sufficient to make it explode. The PEROXIDE OF CHLORINE is also a gas, but of a still more intense colour(6).

Its explosion is more powerful than that of the protoxide, but it does not take place below the heat of boiling water. Both these gases possess powerfully bleaching properties, and in either of them phosphorus will spontaneously burst into flame(7).

Emily. These compounds appear to be dangerous affairs to meddle with, and ought not to be touched by inexperienced hands.

Mrs B. There are other combinations of chlorine which are still more violent than these. Fortunately, however, we may safely talk about such compounds, although the handling of them might be attended with some risk.

CHLORIC ACID is generally formed by passing chlorine through solutions of the alkalies and alkaline earths. It is in its combinations with these bases, called *chlorates*, that we shall witness its most important properties(8). When obtained in a separate form it is a colourless fluid, possessing all the characteristic properties of the acids. It is so easily decomposed, that it has been but little examined. *Perchloric acid* is still less known, although the existence of such a compound is considered as established(9).

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2. What is observed respecting the names of *muriatic acid?*
3. How many combinations of chlorine and oxygen are known?
4. What are they named, and how are they constituted?
5. What is observed respecting the facility of their decomposition?
6. What properties characterize the *protoxide of chlorine?*
7. What particulars are mentioned respecting the *peroxide?*
8. By what process is *chloric acid* usually produced?
9. What further is remarked respecting chloric and *perchloric acids?*

Caroline. Notwithstanding chlorine, in its simple form, is not presented to us by nature, yet if in her operations its compounds are as active as those prepared by the chemist, it may certainly claim a place in company with that all pervading principle, oxygen.

Mrs B. The chemical history of chlorine is one of great interest, but at the same time of great intricacy; and the consideration of it has therefore been deferred until most of the other agents had been made known to you. The changes which it undergoes, or produces, are so involved, as not to admit of a systematic classification, and of course, I shall not attempt any.

I shall next notice some of the chlorides, and may probably find it convenient to incorporate both the chlorates and muriates with them.

Chloride of nitrogen is an oil-like fluid, produced by the union of the bases of the two gases. When the mouth of a receiver containing chlorine, is placed over a solution of muriate of ammonia, the alkali is gradually decomposed, its hydrogen unites with a portion of the chlorine and forms muriatic acid, whilst its nitrogen combines with another portion of chlorine, producing the *chloride of nitrogen*(10). This liquid first forms a film upon the surface of the solution, and afterwards sinks through it in drops. A single drop, the size of a pea, if incautiously handled produces a dangerous explosion. The same effect is likewise caused by mere contact with olive oil, and with many other combustibles, although it is not induced by heat alone, until the temperature exceeds 200°. The chloride of nitrogen is converted, by explosion, into a mixture of nitrogen gas and chlorine. Its discoverer Dulong, and Sir H. Davy, were both seriously injured by experimenting with this most violent of all the explosive compounds(11).

Emily. I recollect another compound resembling oil, which you told us (p. 162) was produced by the combination of *olefiant gas*, or *heavy carburetted hydrogen*, with chlorine. This, like the combination of nitrogen and chlorine, is, I suppose, denominated a chloride.

Mrs B. This oily substance is not called a chloride, but is frequently designated by the term *hydrocarburet of chlorine.* To form it, equal measures of chlorine and of olefiant gas are mixed together; whereupon the two gases gradually disappear, and there is generated a yellow liquid like oil. This substance, however, does not possess any of the properties of the chloride of nitrogen, nor is it properly an oil(12).

Carbon, sulphur, phosphorus, and some other articles may also be converted into chlorides, but I shall pass them by, and proceed to a very interesting salt, formerly called the *hyperoxymuriate of potassa*, but now denominated *chlorate of potassa.*

Chlorate of potassa, better known as the *hyperoxymuriate of potassa*, may be conveniently formed in Woulfe's apparatus (p. 236). By putting into the bottles a solution of caustic potash, and passing into it a stream of chlorine gas, until the solution is saturated, the salt in question will be produced(13).

Caroline. But how can this process form a chlorate? I should suppose that, to effect this, you must pass chloric acid into the solution of potash.

Mrs B. Recollect that water is present, and you may find that by invoking its aid your difficulty will be removed. The hydrogen of the water unites with a part of the chlorine, and forms muriatic acid, which acid combining with potash becomes muriate of potash. The oxygen liberated from the decomposed water, and presented, in its nascent state, to the chlorine,

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10. By what process may we form the *chloride of nitrogen?*
11. What is its appearance, and what are its properties?
12. What is said of the oil-like substance from *olefiant gas?*
13. By what process may *hyperoxymuriate*, or *chlorate*, *of potassa* be formed?

combines with it; and this uniting with a part of the potash, produces chlorate of potassa(14).

Caroline. But I perceive what appears to me a strong objection to that explanation. Chloric acid contains one atom of chlorine united to five atoms of oxygen, and yet each atom of the decomposed water parts with but one atom of oxygen. Whence, then, can the chloric acid derive the five atoms required to produce it(15)?

Emily. Were muriatic acid alone generated, oxygen alone would be given out. Perhaps, therefore, there may be a large portion of muriatic, and but a small portion of chloric acid formed; and this, you know, might afford a sufficient quantity of oxygen to give the five atoms necessary to its composition.

Mrs B. And such appears to be the fact. The quantity of muriate of potassa, which we obtain, is five times as great as that of the chlorate, and consequently, there will be oxygen enough liberated to produce this proportionate quantity of chloric acid(16).

The chlorate of potassa is much less soluble than the muriate, the consequence of which is, that, during the process, a large portion of the chlorate is precipitated in beautiful pearly scales, such as you see in this phial. These crystals are washed to free them from any adhering muriate of potassa, and may, when dried in a gentle heat, be considered as the pure chlorate of potassa(17). Between this salt and nitre, there is a strong resemblance; as there is, indeed, between the nitrates and the chlorates generally.

Emily. This may well be supposed, as they both contain a large quantity of oxygen in a state of very loose combination.

Mrs B. And in the chlorates the union is more loose than in the nitrates; in consequence of which many inflammables will decompose the former, which, under similar circumstances, would not affect the latter, as you will presently see(18).

Caroline. Can we not decompose the chlorate and obtain its acid, by pouring upon it sulphuric acid, just as nitric acid was obtained from nitre?

Mrs B. The decomposition in this case does not stop at the production of the acid. The chloric acid is not merely separated from the potash, but is itself decomposed, and explodes, shivering to atoms any glass vessel in which the mixture is made. It is possible however to obtain the acid in a liquid state, and, therefore, its separate existence is well established(19). As I have before indicated, our experiments with it will be all made with its salts.

I mix a few grains of loaf sugar in powder, with about half its quantity of the chlorate of potassa, and touch the mixture with a drop of sulphuric acid.

Emily. Its combustion was nearly like that of gunpowder, only somewhat more slow. The chloric acid was in this case decomposed by the sulphuric, and the combustion effected by the liberated oxygen; was it not so(20)?

Mrs B. Undoubtedly. Heat, you know, will cause nitre to part with a large portion of its oxygen, but from the chlorate of potassa this gas is obtained in much larger quantity, and in a state of greater purity. To this material the chemist resorts whenever he has occasion to employ oxygen

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14. What is the rationale of its formation?
15. What objection is urged against this explanation?
16. By what reasoning is this objection obviated?
17. How is the salt obtained in the crystalline form?
18. What strong resemblance is there between this chlorate and nitre?
19. What takes place when sulphuric acid is poured upon this salt?
20. What experiment may be performed with the chlorate and sugar?

gas in its most perfect form. One hundred grains of the chlorate afford about twenty-five grains of the gas, or, in bulk, about seventy-five cubic inches(21).

Caroline. The famous match-lights, which I have so often used, must, I think, depend upon this chlorate for their action.

Mrs B. Entirely; these matches, after being covered with sulphur, are dipped into a mixture of chlorate of potassa, sugar, and sulphur, made into a paste with gum water. They are then dried, and when touched with sulphuric acid, instantaneously inflame.

Caroline. The phial then, into which we dip them must contain sulphuric acid(22). But what causes it to get out of order, as it very soon does?

Mrs B. The sulphuric acid, by the frequent opening of the phial, attracts moisture from the atmosphere, and thus becomes too much diluted to produce the intended effect.

By the aid of sulphuric acid, the chlorate may be made to give out its oxygen under water, and if this takes place in contact with phosphorus, its combustion will be effected. At the bottom of this glass of water are some small pieces of phosphorus, covered with some of the salt; I pour some strong sulphuric acid down the side of the glass, and the combustion commences the moment the acid touches the chlorate(23).

Emily. How wonderful it is to see flame bursting out under water, and how gratifying to be able to account for it! We know now, through your kind instructions, that the sulphuric acid decomposes the salt, by combining with its potash, and that the disengaged oxygen effects the combustion of the phosphorus.

Mrs B. Very well explained; and with a little more reflection you would have added, that the increase of temperature resulting from the mixture of the sulphuric acid and water, powerfully aids in promoting the combustion(24).

Friction, or a blow, will enable many combustibles to decompose this chlorate. Observe, I put two or three grains of the salt, and about half the quantity of flowers of sulphur into this iron mortar; now I will rub them together, with the pestle.

Caroline. Astonishing! what a succession of reports; they sound like a number of pistols fired one after another(25).

Mrs B. If I mix the pulverized chlorate and the sulphur intimately together, then collect the mixture in a heap in the mortar, and strike it with the pestle, the report will be like that of a gun. Most of the metals, mixed with the chlorate, in the form of filings, and treated in the same way, will also produce explosions. Charcoal, likewise, when in powder and thus mixed, is inflamed, either by friction, or by a blow. Its action, however, is less violent than that of sulphur, or the metals(26).

Caroline. Might not a gunpowder much stronger than that in use be produced by employing the chlorate of potassa, instead of nitre?

Mrs B. Yes: and this has been actually attempted; but several individuals lost their lives from the explosion of the materials whilst they were being mixed together(27).

Emily. The powder now used produces so much desolation, that we need not regret the difficulty of preparing such a kind as would be still more destructive.

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21. What is said on the procuring oxygen from the chlorate of potassa?
22. How are the match-lights prepared from this salt?
23. How may phosphorus be made to burn under water by its aid?
24. In what way is this phenomenon explained?
25. When the chlorate is rubbed up with sulphur, what ensues?
26. What explosions are mentioned as produced by its aid?
27. Has it been attempted to use it instead of nitre, in gunpowder?

Mrs B. A kind of powder which inflames by a blow, instead of by flint and steel, and called *percussion powder*, has been made by substituting the chlorate for the nitrate of potassa. This powder was, for a while, employed for the priming of percussion guns; but fulminating mercury (p. 197) is now generally used for that purpose, it having been found to be much better adapted to the purpose than the former(28).

After having thus explained to you the properties of the hyperoxymuriate, or chlorate of potassa, I shall not introduce the other alkaline and earthy chlorates, because they are so analogous in their general properties as not to offer any thing which would be particularly interesting to you. We have yet, however, something to say respecting the *muriates* and *chlorides*, and will in the first place recur to that with which you are already the best acquainted; I mean the MURIATE OF SODA.

Caroline. Your injunction at the commencement of our conversation today, leads us to anticipate some difficulty as regards the constitution of this salt, but with your aid we may confidently hope that we shall not find it insurmountable.

Mrs B. The received doctrine as regards *muriate of soda* is, that, in a perfectly dry state, what we call by that name, is really a CHLORIDE OF SODIUM; that when this chloride is dissolved in water, it is, in the mere act of solution, converted into *muriate of soda;* and that if the water be again evaporated, the muriate of soda is then decomposed, and *chloride of sodium* reproduced(29). I need not inform you what is the chemical difference between those two compounds.

Emily. That I think we understand perfectly. The chloride of sodium consists of metallic sodium, united to chlorine, and it contains nothing therefore but these two substances; but the muriate of soda is composed of the oxide of sodium (common soda) combined with muriatic acid, which, on its part, consists of hydrogen and chlorine. Muriate of soda, therefore, contains sodium, chlorine, oxygen, and hydrogen(30).

Caroline. I shall require some unequivocal testimony, before I have perfect faith in these sudden and imperceptible transitions.

Mrs B. Pure metallic sodium burns very readily in chlorine; and when its combustion is effected *without the presence of any moisture whatever*, the product is identical with common salt. Can this, therefore, which contains neither oxygen nor hydrogen, be a muriate of soda?

Emily. Assuredly not, because neither of the constituents of water is present, or concerned in the process. It seems plain that you can, in this case, obtain nothing but the *chloride of sodium*(31).

Mrs B. Yet, when you dissolve this chloride of sodium in water, if you pour sulphuric acid into the solution, muriatic acid will be expelled, and sulphate of soda formed. It appears, therefore, necessarily to follow, that when the chloride of sodium comes into contact with water, this fluid is decomposed, that the sodium becomes soda by combining with its oxygen, and that the chlorine becomes muriatic acid by combining with its hydrogen. When the water is evaporated, the hydrogen and the oxygen are expelled, and being presented to each other in their nascent state, again unite, and form water, whilst the sodium and the chlorine are also restored to their former state(32).

Caroline. Such evidence certainly "must give us pause," and induce us to study this particular subject with great care.

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28. Of what does the priming of percussion guns consist?
29. What is the received opinion respecting *muriate of soda?*
30. In what respects do *muriate of soda*, and *chloride of sodium* differ?
31. What proof is given that common salt, when dry, is a chloride?
32. What shows that it becomes a muriate by solution?

Mrs B. Dismissing, for a while, our theoretical discussion, and returning to truths of a more palpable kind, we will say something upon the natural history of this most common, and most valuable of all the saline compounds.

Muriate of soda is principally obtained from sea-water, either by natural or artificial evaporation, but it is seldom perfectly pure, as a number of other salts exist in the ocean, some of which are bitter and *deliquescent.* Sometimes a considerable portion of these foreign salts is allowed to remain with the muriate of soda, in which case they not only injure its taste, but cause it to attract moisture, and thereby render it unfit for preserving meat or fish. These foreign salts are principally the muriates of magnesia and of lime, and the sulphates of magnesia and of soda(33).

Caroline. But all the salt of our tables is not derived from the sea, as there are immense mines of it, and a great number of salt springs in the interior of many countries. I recollect an account of a mine in Poland which has been worked for centuries, and which runs to a great distance under ground, with columns, houses, churches, and other establishments, all cut out of the solid salt, and glistening with surprising brilliancy, from reflecting the light of the lamps and torches which the miners are compelled constantly to burn(34).

Mrs B. Salt, from its great value to man, has been adopted as the emblem of every thing that is excellent and worthy, in the human character; and a benevolent Providence has diffused it through countries remote from the ocean, by the formation of mountains, mines, lakes and springs, from which this necessary substance may be obtained.

Its uses are numerous; it preserves for years those perishable animal substances which, without it, could not, sometimes, be kept for a single day. It not only heightens the flavour of our food, but contributes to health by promoting digestion and nutrition. Our domestic, and other, animals have a natural fondness for it, and derive advantage from its use. To the arts it supplies muriatic acid, sulphate of soda, carbonate of soda, chlorine and chlorides for bleaching. It is employed in the manufacturing of calomel, and other chemicals; the potter applies it to the glazing of certain kinds of earthenware; and the physician administers it as a remedy in certain diseases, and destroys contagion by liberating its chlorine(35).

Emily. The article which you have just placed upon the table, with the label of *sal ammoniac* is not quite a stranger to us, as you used it in the preparation both of ammonia and of its carbonate: you also gave us some account of its origin, and of the means by which it is manufactured (p. 169).

Mrs B. You are fully aware that its proper chemical name is the MURIATE OF AMMONIA. My principal reason for introducing it now, is to exhibit its formation by the mere mixture of gaseous muriatic acid and ammonia: the moment they come in contact with each other, their bases will combine, and form the solid salt. I employ for this purpose the same apparatus which was used in preparing the carbonate of ammonia (p. 171).

Caroline. I recollect being much interested in that experiment, as evincing, in a very striking manner, the effect of chemical combination in changing the form of bodies ; two gases being instantaneously brought into the solid state.

Mrs B. And in the present instance the change is still more remarkable, as both the ammonia and the muriatic acid possess an extremely pungent odour, which is entirely lost in their state of combination, which, you know, is not the case with the carbonate of ammonia.

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33. What salts does sea-water contain, besides the muriate of soda?
34. From what other sources is common salt procured?
35. Enumerate some of the uses of this substance

apartments to be disinfected, and to close them for a considerable length of time. The chloride of lime, however, performs its office without requiring any such precaution.

Caroline. Every man, woman and child ought to be made acquainted with a process so very beneficial, and so frequently needed.

Mrs B. The chloride of lime is now kept by the apothecaries, and is a cheap article. It may be made ready for use when wanted by dissolving four ounces of it in a pint of water. A wine glass full of this solution added to three quarts of water, or one part in forty, will effectually remove the effluvia arising from animal or vegetable putrefaction. In hospitals, anatomical rooms, and similar places, the solution may be sprinkled about, and will rapidly purify the atmosphere(43). The smell of bilge water on board of ships, that of paint in newly painted rooms, and the offensive odours arising from various causes, are in this way not merely removed, but their sources also purified. In cellars, and similar places, a portion of the dry powder may be thinly scattered upon the floor, and the same may be done with the most perfect success in those manufactories which are unhealthy and offensive(44).

Emily. How delightful and ennobling are such discoveries! But I am at a loss to perceive by what agency the chlorine is disengaged from the lime, as there is no acid added to dislodge it.

Mrs B. It appears that the carbonic acid which is always disengaged with putrid effluvia, is, of itself, sufficient for that purpose. It combines with the lime, converts it into a carbonate, and thus expels the chlorine, but so gradually as scarcely to allow its odour to be perceived(45).

I have now placed before you the most important of the combinations of chlorine, with the exception of *aqua regia,* and of those substances formed by the union of chlorine with mercury; but I must not dismiss the subject without saying something of each of these. That which relates to mercury was purposely omitted when we treated of the metals, because you were then unacquainted with chlorine.

Caroline. I recollect your telling us that *aqua regia,* was by the chemist called NITRO-MURIATIC ACID, and that it was the only acid capable of dissolving gold or platinum.

Mrs B. NITRO-MURIATIC ACID is produced by merely mixing nitric and muriatic acids together; and the effect of this mixture will be shown by an easy experiment, which I have once performed, and will now repeat(46).

I have here two wineglasses; into each I put a leaf of gold: I now pour nitric acid on one of the leaves, and muriatic acid on the other. The gold you perceive remains unchanged: it will soon disappear, however, if I pour the contents of the two glasses together(47).

Emily. It has already dissolved, not a vestige being left: the acids also appear of a much deeper colour, and emit a stronger odour than they did before their mixture.

Mrs B. Gold leaf, when immersed in a vessel of gaseous chlorine, combines with it, and is converted into a chloride, and in the present instance, also, chlorine is the agent which dissolves the gold. You have seen that neither the nitric nor muriatic acid alone will produce this effect(48).

Caroline. But the chlorine is already combined with hydrogen to form

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43. How is it used as a disinfecting agent?
44. What is remarked respecting the effects produced by it?
45. How is the chlorine liberated in these cases?
46. How is *aqua regia,* or *nitro-muriatic acid,* formed?
47. By what experiment is the power of this acid shown?
48. What appears to be the solvent of the gold?

muriatic acid, and if the gold decomposed the acid and combined with its chlorine we ought to obtain hydrogen gas.

Mrs B. It is the oxygen of the nitric acid, and not the gold which disengages the chlorine. When the two acids are poured together, a part of the oxygen of the nitric acid combines with the hydrogen of a portion of the muriatic acid, and the latter, of course, becomes chlorine, whilst the former is reduced from the state of nitric, to that of nitrous acid. This acid and chlorine are consequently disengaged, and it is from these that the colouring of the nitro-muriatic acid and the red fumes proceed. The chlorine which is liberated dissolves the gold(49).

If after mixing the two acids, we were to heat them sufficiently to expel the nitrous acid and the chlorine, the remaining acid would have no power to act upon gold.

I will now briefly explain to you the formation of corrosive sublimate, and of calomel, which are both CHLORIDES OF MERCURY: there is, however, this difference between them, the quantity of chlorine contained in *corrosive sublimate* is twice as great as that in *calomel.* The latter is the *chloride of mercury;* the former (corrosive sublimate), the *bichloride*, or *perchloride*, *of mercury*(50).

Emily. These then afford another instance of a great change of properties by merely changing the proportions of the component parts of a body. Corrosive sublimate is, we know, a most virulent poison, whilst calomel is safely used as a medicine in considerable quantities.

Mrs B. Mercury, when sufficiently heated, undergoes combustion in chlorine, burning with a pale red flame; the product being the *perchloride of mercury*, or corrosive sublimate(51). This perchloride may be converted into *protochloride of mercury*, or calomel, by rubbing it in a mortar with about its own weight of metallic quicksilver. The two substances will combine together, each atom of chlorine taking to itself an atom of mercury, and the union is completed by sublimation. This is not the process by which these preparations are manufactured, but it serves to give a direct view of their composition(52).

Caroline. You have several times spoken of the analogy between chlorine and oxygen, and I have sometimes wondered at their not having been treated of together; but the delay in introducing chlorine no longer surprises me, as its combinations and changes render its chemical history an extremely difficult subject to comprehend, and one which would therefore have been a complete blank to us at an earlier period.

Mrs B. But few doctrines in chemistry have encountered greater opposition than that of the simple nature of chlorine; and at the time when the name of oxymuriatic acid was changed to that of chlorine, chemists were not acquainted with any other substance, excepting oxygen, which supported combustion. Two have, however, been subsequently discovered which appear to be simple, and are so analogous to chlorine in their general properties, as powerfully to sustain its claim to be considered as a simple or elementary body. These two substances are *Iodine* and *Bromine*(53).

Emily. This discovery must have been very gratifying indeed to the founders and advocates of the new theory.

Mrs B. IODINE is a solid, which is obtained in minute scales, or grains, of a bluish-black colour, and a metallic lustre. It is so friable as to be

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49. By what reaction is the chlorine disengaged?
50. What are *corrosive sublimate* and *calomel?*
51. How may the direct formation of corrosive sublimate be effected?
52. How may this be converted into the *protochloride* or calomel?
53. What discoveries lend aid to the theory of the simple nature of chlorine?

easily bruised between the fingers. It volatilizes, though slowly, at common temperatures. When moderately heated, it is converted into a vapour of a rich violet colour. I have some grains of it closed up in this flask, which I will heat by holding it over the lamp, turning it about to warm it equally(54).

Caroline. You may indeed call that a rich colour, I think it the most splendid purple I have ever witnessed.

Mrs B. Its name is derived from a Greek word indicative of its colour. Like chlorine, its principal source is the ocean, as it is generally procured from the ashes of sea weeds, although found in some other combinations. Its odour is very similar to that of chlorine, which it resembles in being acrid and corrosive. In its affinities also it is strikingly similar, decomposing water and forming with its hydrogen a gaseous acid, called *hydriodic acid gas.* With oxygen it produces *iodic* acid, and with chlorine *chloriodic* acid. It combines with nitrogen, furnishing an explosive *iodide of nitrogen;* and the parallel between it and chlorine might be extended through nearly all its combinations(55).

Emily. Under what circumstances does *iodine* appear to be a supporter of combustion?

Mrs B. Its agency as a supporter of combustion is very limited. Potassium, and a few other substances, however, burn in it with the usual appearances; and its combinations with bases generally, are analogous to those produced by the acknowledged supporters of combustion(56).

Caroline. If *bromine* bears as strong a likeness to chlorine as iodine does, they certainly must be allowed to form a well characterized class.

Mrs B. The similarity is so great, that its discoverer thought it probable that *bromine* was a compound of chlorine and iodine. Upon the most careful investigation, however, its character as a simple substance appears to be well established(57).

Bromine is a fluid of a blackish-red colour. It is volatile, and when volatilized, its vapour is of a bright red, resembling that of nitrous acid. It is found in the waters of the sea and of saline springs, and also in those sea weeds which contain iodine. It combines both with hydrogen and with oxygen, forming acids which possess nearly the same affinities with those formed by iodine and chlorine with the same principles. Potassium, tin, and antimony burn in it, and are converted into *bromides.* Like its congeners, it has resisted every attempt at decomposition(58).

Oxygen, chlorine, iodine, and bromine are the only undecompounded bodies which are electro-negative, and which consequently pass to the positive pole when placed in the voltaic circuit.

Emily. This last character seems, by a very peculiar resemblance, to unite these four substances together, as belonging to one family. All the other simple bodies, numerous as they are, are carried by their electric state, to the negative pole of the voltaic battery, whilst these stand alone, as being carried to the positive pole(59).

Mrs B. Before finally parting with bromine and iodine, I ought to inform you that the latter has been advantageously applied in the arts as the foundation of some very brilliant colours, particularly in the printing of calicos. It has also taken a place in the materia medica, as an article

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54. What appearances are exhibited by *iodine?*
55. Whence is it obtained, and what are its resemblances to chlorine?
56. In what instances is it a supporter of combustion?
57. What proves the resemblance between iodine and *bromine?*
58. What is said of the appearance and combinations of bromine?
59. What special character unites oxygen, chlorine, iodine, and bromine?

acting more directly and powerfully on the absorbents than any other in the whole list of remedial applications(60).

CONVERSATION XXV.

ON THE GENERAL PROPERTIES OF SALTS.

Of what a Salt must consist. What were formerly called Salts. Sapidity of Salts dependent upon their Solubility. Circumstances which control the Solubility of a Salt. Deliquescence, Efflorescence, and Permanence. Water of Crystallization. Anhydrous Salts. Effect of hot Water in dissolving Salts. Formation of Regular Crystals. Two Solid Salts rendered fluid by Mixture. Incompatible Salts. Separation of Salts from each other. Salts dissolved in a saturated Solution. Double Salts. Definition of a Crystal. Some Crystals not imitable by art.

Mrs B. In our conversations upon the elementary principles of bodies, and of the compounds which they form by their union, you have become acquainted with a considerable number of that large class of substances which the chemist denominates SALTS. There are, however, some facts in regard to this very important class of bodies which have been but briefly noticed, and others that have not been even hinted at: these will form the subject of our inquiries to-day. You undoubtedly recollect the general constitution of a salt.

Caroline. Perfectly, I believe. Salts are substances which consist of an *acid* united to a *base*(1).

Mrs B. The term salt was formerly used in a manner altogether vague. Almost every substance which possessed sapor, was soluble in water, and crystallizable, was so called. The solid acids, and alkalies, as well as their combinations, were therefore classed with the salts(2). Under such a nomenclature a salt might be compounded of two simple substances only: thus potassa, which is an oxide of potassium, and phosphoric acid, which is oxygenated phosphorus, were considered as members of this family. Every salt, according to the present arrangement, must be compounded of, at least, two compound substances; every acid and every salifiable base being itself a compound(3).

Caroline. Then every salt must consist of, at least, four different simples.

Emily. Are you not too quick in your conclusion, Caroline? If we combine the potassa and the phosphoric acid, and form phosphate of potassa, but three undecompounded substances will be contained in the resulting salt, as oxygen was one of the ingredients in both the combining articles(4).

Caroline. You have indeed fairly caught me, Emily, and I, in my turn, will venture to impugn the definition of the chemists, and say that salt itself is no salt; for are we not told that the very article from which the

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60. To what uses has iodine been applied?
1. How may *a salt* be defined?
2. To what substances was the term formerly applied?
3. What marked difference is there between the former and the present arrangement?
4. Does it follow that a salt must contain four simple substances?

name is taken, the muriate of soda, is actually a chloride of sodium, and consists therefore of two elementary substances only(5)?

Mrs B. Very well managed, Caroline. If the constitution of common salt should be unequivocally proved to be such as is supposed in the theory to which you have alluded, this very substance must be banished from the class to which it has given a name; but neither its usefulness or its importance will suffer any diminution from this cause, nor will the definition of the chemist be impugned by transferring the chloride of sodium from the company in which it has hitherto held a place into another corps. You may recollect, also, that it will resume its former station in nearly the whole of its active operations, as the water which dissolves it will also convert it into the muriate of soda(6).

Emily. To give the name of salt to a substance which is altogether insipid, still seems to do some violence to the idea which the word has commonly conveyed to the mind; as no other test of saltness has hitherto been known to us but the peculiar taste possessed by a substance; and this taste has always been more or less associated with that of common salt.

Mrs B. You now know, however, that the class to which any substance belongs must depend upon its chemical constitution, and not upon a mere accidental character which may belong to the individual. The sapidity of a salt depends upon its solubility, and consequently those which are entirely insoluble in water must be altogether insipid. A solid substance put into the mouth is tasteless if the saliva will not dissolve it, and the intensity of its taste will be governed by the facility with which it is dissolved(7).

Caroline. The facility or difficulty of solution must depend principally upon the affinity between water and the salt. Some salts I know become moist, and even pass into the liquid state, by mere exposure to the atmosphere, and these I recollect you have called *deliquescent salts.*

Mrs B. The cause you have assigned, together with that of the cohesive attraction of the particles of a salt, are the two circumstances which govern its solubility. You will at once see that the more forcibly the particles of a salt adhere together, the greater must be the difficulty with which water or any other agent can separate them(8).

As respects the influence of atmospheric air upon them, salts are divided into *deliquescent*, *efflorescent*, and *permanent*(9). Carbonate of potassa, muriate of lime, and many others are *deliquescent.* Other salts, instead of acquiring water from the atmosphere, lose a portion of that with which they were combined, and instead of retaining their solid crystalline form, fall into powder. This process is denominated *efflorescence.* Sulphate of soda, and sulphate of iron, are both efflorescent. Those salts which undergo no alteration by exposure to the air are called *permanent*(10).

Caroline. But if a salt loses a portion of the water which was combined with it, it loses one of its constituents and must therefore be decomposed.

Mrs B. Perhaps this effect ought to be called a *disintegration*, rather than a *decomposition* of the salt; as by parting with water it merely loses its crystalline form, whilst its essential ingredients, the acid and the base, remain united. Water is absolutely necessary to the crystallization of most salts, combining with them in definite proportions. This proportion of

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5. What remark is made by Caroline respecting common salt?
6. What is the reply to this observation?
7. Why are some salts sapid, and others tasteless?
8. Upon what circumstances does the solubility of a salt depend?
9. How are salts classed as regards the influence of air upon them?
10 What is intended by the terms *efflorescent*, *deliquescent* and *permanent*?

water is called the *water of crystallization*, and whilst it is retained as such, it exists in the solid form(11).

Emily. I recollect you called those bodies *hydrates*, with which water is so intimately combined as to exist in them as one of their essential components(12). Are all crystallized salts hydrates?

Mrs B. By no means; for although most crystallized salts contain water as an essential ingredient, this is not the case with all. Those salts which do not contain any are called *anhydrous*. Nitre and common salt are both *anhydrous*(13). In some instances, the same salt may exist in the crystalline form in both states; but, in this case, the form of the crystal, and some other characters of the salt, will be changed. The common borate of soda is a hydrate, but there is also an *anhydrous borate of soda;* the former is slightly efflorescent, the latter is permanent. Common crystallized sulphate of lime is also a hydrate, but there are likewise crystals of *anhydrous sulphate of lime*(14).

Caroline. I should suppose that those salts which are soluble would, in all instances, be dissolved in much larger portions in hot than in cold water, as heat itself is a powerful solvent.

Mrs B. You may well draw such an inference, from the general agency of heat, and it is justified by the greater number of facts; but still it is not a universal truth. The chlorate of soda, the phosphate of ammonia, the muriate of soda, or common salt of our tables, and some others, are dissolved in nearly the same proportions in cold as in boiling water(15); whilst there are some salts that dissolve in quantities absolutely unlimited, when the heat is at the boiling point.

Caroline. This seems equivalent to saying that they will dissolve in no water at all; as a single drop of water must, in this case, be capable of dissolving a thousand pounds of such a salt!

Mrs B. Such salts *dissolve in their own water of crystallization*, when heated to the boiling point, and, of course, the quantity dissolvable is unlimited; as each crystal carries with it the portion of water necessary to its own solution(16).

Emily. In such salts the quantity of water of crystallization must, I apprehend, be very great.

Mrs B. The solution does not depend entirely on the quantity of water of crystallization, but, principally, upon the nature of the salt itself. More than half the weight of crystallized sulphate of soda (Glauber's salt) consists of water, its amount being 56 per cent, yet it is not soluble in its own water of crystallization(17).

Caroline. I have occasionally seen Glauber's salt thrown away, under the impression that it was spoiled, because it had become a loose white powder, and I now perceive that it had merely parted with its water of crystallization.

Mrs B. Such a salt is worth more per pound in its effloresced than in its crystalline state, as the weight lost is merely that of water, and if a quantity of boiling water, just sufficient to dissolve the salt, were poured upon it and the solution allowed to cool, a crop of beautiful crystals would be ob-

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11. What is water of crystallization, and what the actual effect of efflorescence on a salt?
12. When are bodies denominated hydrates?
13. What is remarked of salts in this particular?
14. What is observed respecting the two states of the same salt?
15. Are all salts dissolved more abundantly by hot than by cold water?
16. What salts dissolve in unlimited quantities in hot water?
17. Does this depend on the quantity of water of crystallization?

tained; as boiling water will dissolve nearly four times the quantity which cold water can retain(18).

Emily. I recollect that in our conversation on the subject of latent heat, (p. 76,) there was an illustration of this fact, in the crystallizing of Glauber's salt from its solution, but the crystals then formed appeared to be a mere confused mass.

Mrs B. The production of beautiful well-formed crystals is a slow process, and it is necessary that the solution should be at perfect rest, in order that the particles of the salt may arrange themselves in the symmetrical way necessary to the perfection of the process. In the experiment to which you allude, the crystallization was almost instantaneous(19).

Caroline. This symmetrical arrangement called crystallization appears to me to be a very curious thing, and I should be much gratified to learn something about the process itself; I suppose I must not say about its cause?

Mrs B. I intend presently to gratify you in this particular, but have not yet completed what I have to say respecting some other properties of salts and their solutions. I am about to show you an experiment with two crystallized salts, upon the rationale of which you may exercise your ingenuity; it is the reverse of the *chemical miracle* formerly shown to you (p. 76), as it consists in the conversion of two solids into a fluid, by mixing them together. I take equal portions of crystallized sulphate of soda, and muriate of ammonia; both, of course, in a solid and dry state. I now rub them intimately together in a mortar, and you see the result.

Emily. That is extremely curious, they are actually in a state of solution, as much so as though you had poured water upon them(20).

Mrs B. I think that by the aid of our present conversation, you will be able to account for this change. I will observe, however, that a double decomposition has taken place, and that, instead of sulphate of soda, and muriate of ammonia, we have produced a muriate of soda and a sulphate of ammonia, these two salts being now in a state of mixture.

Caroline. In the decomposition of the original salts, their water of crystallization must have been set at liberty, and its quantity must have been sufficient to dissolve the new salts which are formed(21).

Mrs B. You have given the rationale correctly, as I was convinced you would. These double decompositions, which result from the mixture of two different salts, have given rise to the name of *incompatible salts*, tables of which you will find in some of the treatises on chemistry. By *incompatible* salts are meant those which cannot exist together in solution without mutual decomposition. Such were the salts which we just now mixed together(22).

Emily. The muriate of soda which is contained in the water of the ocean, is mixed with a great number of other salts. Nitre likewise, and in fact most of the salts in their crude state are contaminated by the presence of others; upon what principle is their separation effected?

Mrs B. To effect this separation the chemist takes advantage of the difference in the solubility of the respective salts. When these mixed salts have been dissolved, the water is evaporated to a certain extent, and by merely allowing the solution to remain at rest for some days, that salt which is least soluble is deposited in the crystalline form. From these crystals the *mother water*, as the solution is now called, may be poured off. This may be still further evaporated, and made to deposite a second crop of salt, of a kind

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18. What is remarked respecting an effloresced salt?
19. Upon what does regular crystallization depend?
20. What two solid salts become fluid by mixture?
21. In what way is this solution explained?
22. When are salts said to be *incompatible?*

more soluble than the former, and which was therefore retained by the water, until its quantity was reduced by the second evaporation. By repeated solutions and crystallizations, in this way, the respective salts may be obtained in a separate state, which, but for the difference in their solubility, must forever have remained mixed with each other. *The refining* of nitre and other salts is thus effected(23).

Caroline. I am aware that it would be impossible to separate the crystals of different salts which were grouped together; but if there are two or three different salts in the same solution, and the whole of the water was to be evaporated, would not the particles of each salt unite to those of its own nature, and form distinct crystals?

Mrs B. They would, and their different forms may frequently be seen in the mass of crystals. This fact is very satisfactorily exhibited where one of the salts is coloured, as I am prepared to show you. I have dissolved in the same hot water, portions of nitre, which is colourless, and of sulphate of copper, which is blue; this solution I have poured into a plate, and suffered it to cool. The salts, you see, have crystallized separately(24).

Emily. How beautiful they appear, and how distinct! They look like white and blue gems grouped together, and are as completely distinguished by their respective forms as by their colours.

Caroline. Nothing certainly could exemplify more strikingly, or more satisfactorily, the controlling attraction which the similar particles exert towards each other. Aided by the difference in colour, we might now separate the salts from each other, almost perfectly(25).

Mrs B. You are aware that water at a given temperature will dissolve only a definite portion of a salt, and that it is then *saturated.* It is a fact, however, that water saturated with one salt, may still dissolve a quantity of a second, and that the dissolving of this last will enable it to combine with more of the former. Thus, for example, water saturated with common salt, will afterwards dissolve nitre, and, when it has done so, will take up an additional portion of the muriate of soda(26).

Emily. That is indeed curious; but I suppose it can be satisfactorily accounted for.

Mrs B. It appears to result from an attraction existing between the two salts, which, added to the attraction of the water, increases the power of combination. When the solution of common salt has, from this cause, dissolved a portion of the nitre, this, in its turn, lends its attractive influence to the water, and enables it to increase its charge of the muriate of soda(27).

Caroline. But if these salts can be again separated by crystallization, the attraction which promoted their solution must still have been insufficient for their decomposition. I can very well conceive of such an attraction, and think that its existence must aid in accounting for many phenomena(28).

Mrs B. The existence of such an attraction is frequently made manifest. Even those salts which are *incompatible* may, by a very simple precaution, be mixed together without decomposing each other; all that is necessary being to dilute them with a large quantity of water. They will then remain together unchanged, yet the attraction of their elements must still exist, although it is counteracted by the water employed for their solution, in consequence, probably, of its removing their respective particles very far from each other(29).

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23. How may salts in solution be separated from each other?
24. Describe the experiment of nitre and sulphate of copper.
25. What fact does this experiment serve to illustrate?
26. What is said of a solution saturated with one salt?
27. What explanation is given of this phenomenon?
28. What is remarked respecting an attraction of this kind?
29. When may incompatible salts exist together in solution?

Emily. Are there no instances in which different salts, when mixed together in solution, combine and form one common compound salt, inseparable by crystallization?

Mrs B. There are some such; and the resulting combinations have been usually called *triple salts;* but perhaps the term *double salts* would give a more correct idea of their composition. Such salts usually consist of one acid united to two different bases(30). Common alum, formerly noticed, (p. 179), is one of these. It is usually called the *sulphate of alumine,* but more properly *sulphate of alumine and potash,* as it consists of sulphuric acid united to both alumine and potassa. Rochelle salt, also, has a double base, consisting of potash and soda, which are united to a vegetable acid called *tartaric acid.* This salt, therefore, is properly a *tartrate of potash and soda.* These may suffice as examples of the *double salts,* which do not form a very extensive class(31).

We have now touched upon the most important points respecting the salts as a class. The greater number of them are capable of crystallization, but this is a property which they possess in common with most of the bodies in nature. We are more familiar, however, with saline than with other crystals. But tell me, Caroline, what do you understand by a crystal?

Caroline. By a crystal, I understand a body which, in becoming solid from its solution, assumes a certain regular symmetrical form, with flat sides and regular angles, appearing as though it had been formed by art(32).

Mrs B. Your definition is very good, and, I may add, unobjectionable, provided you employ the term solution in its broadest sense. Many articles crystallize which are dissolved by heat alone. Thus several of the metals assume a crystalline form, on being allowed to cool slowly after having been fused. Sulphur also, and many other substances which undergo fusion, exhibit the same tendency. The particles of the greater number of those solids which are capable of sublimation, likewise arrange themselves in symmetrical forms, as they consolidate by cooling(33).

Emily. I have often admired the crystals in cabinets of minerals, where many of the native metals, and the solid insoluble earths, are seen moulded by nature into regular and beautiful shapes. It seems difficult to conceive how insoluble substances should assume these forms.

Mrs B. Nature, for the perfection of her operations, has a variety of means, and an extent of time, at her disposal, which set at nought the labour of man, during his brief existence. A substance which would require for its solution many thousand times its weight of water, may by us be well deemed insoluble; as under our control it might not, during the continuance of our lives, form a visible crystal. Art, therefore, must completely fail when she would essay to imitate nature in such a work(34).

The subject of the formation of crystals, by the aggregation of their constituent particles, is one which is well worthy of your examination. It is sufficiently extensive, however, to deserve the devotion of more time to it than the remainder of the present evening would admit. The salts have detained us longer than I had anticipated. I therefore postpone the subject of crystallography until to-morrow, although I had anticipated, and prepared for, its introduction to-day.

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30. What are *double salts,* and how may they be formed?
31. What examples are given of the formation of double salts?
32. What is a *crystal* defined to be?
33. Under what circumstances do some metals and other solids crystallize?
34. Why cannot we imitate some natural crystals?

CONVERSATION XXVI.

ON CRYSTALLOGRAPHY.

Advantages derived from Crystallography. Bodies in general susceptible of Crystallization. Different Forms assumed by different Bodies. Primary and Secondary Forms. Integrant Particles, or Molecules. Derivation of the Rhombic Dodecahedron from the Cube. Conversion of the Octahedron into a Cube, and of the Cube into an Octahedron by mechanical Division. Dr Wollaston's Theory of the Formation of Crystals from spherical Particles. Exemplified in the Piling of Balls. Illustration of the Production of various Crystalline Forms in this way.

Mrs B. The crystalline form is assumed by so large a number of substances, and appears under aspects so different in different bodies, as to have supplied us with a character by which we are frequently enabled to distinguish them from each other. The composition of a body is thus frequently ascertained without the labour of analysis(1). Most, and probably the whole of the simple solids are capable of crystallization, and there is not any body which, either alone or in combination, does not admit of that arrangement of its particles which presents it to us with symmetrical and well defined faces and angles(2).

The science, the object of which is to inquire into the laws which obtain in the formation of *crystals*, is called CRYSTALLOGRAPHY. It is one of considerable intricacy, and which has occupied the attention of many of the ablest philosophers. Without attempting to follow them in their abstruse speculations, we may advantageously survey the outlines of their discoveries.

Emily. Do not the same substances always assume the same form when they crystallize?

Mrs B. Every solid that is susceptible of crystallization, has a tendency to assume a particular shape. Thus, common salt, when most perfectly crystallized, forms regular *cubes;* nitre has the shape of a *six-sided prism;* alum that of an *octahedron;* whilst carbonate of lime produces a regular *rhomboid.* The same substance however is frequently found under a great variety of forms: thus we have carbonate of lime in *six-sided prisms,* in *three or six-sided pyramids,* and in a great number of other shapes(3).

Caroline. That fact destroys all my fine theory, for I had supposed that the shape of the crystal depended upon that of the atoms of which it is composed; as for example, by putting a great number of small cubes together, we might easily make a cube of any imaginable size.

Mrs B. It may be some satisfaction to you to be told that, whether your theory be true or false, the fact which I have mentioned does not, in the slightest degree, militate against it; as all the forms of carbonate of lime to which I have alluded, may be produced by the combination of rhomboidal crystals. It is a fact, also, that we can take one of these more complex crystals, a six-sided prism for instance, and divide it, mechanically, into perfect rhomboids(4).

Caroline. I am indeed pleased that my theory has escaped so far; it has already outlived several of its predecessors.

Mrs B. From the cause stated, the forms under which crystals appear

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1. What advantage does a knowledge of crystalline forms afford?
2. Do bodies in general undergo crystallization?
3. What is said of the crystalline forms of the same body?
4. What is remarked respecting crystals of carbonate of lime?

have been divided into *primary*, and *secondary*. By the *primary form* is intended that into which a crystal may be reduced by mechanical division, or to which it may be proved, by calculation, that it is reducible. By *secondary forms* are intended all those which result from the various combinations of the primary crystals. The first are but few in number; the second are very numerous, in consequence of the many different ways in which the primitive crystals may be piled upon each other(5).

Emily. These wooden models are intended, I suppose, to show the various primitive forms.

Mrs B. That is their principal, but not their only, design, as you will presently learn. There is some difference of opinion respecting the actual number of primitive forms, but, most generally, they are confined to six, and this arrangement we shall follow(6).

The FIRST is the *parallelopipedon*, or a figure terminated by six faces, the opposite ones being all parallel to each other. This includes three principal varieties; the *cube*, the *four-sided prism*, and the *rhomboid* (Fig. 1, 2, and 3), which are those before you.

PARALLELOPIPEDONS.

Cube.

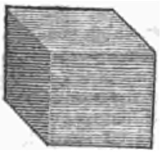

Fig. 1.

Four-sided Prism.

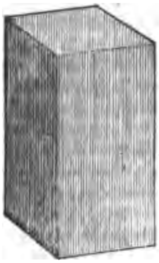

Fig. 2.

Rhomboid.

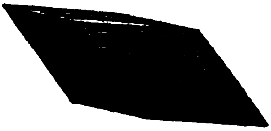

Fig. 3.

Caroline. The similarity between the two first of these is very apparent, as two cubes joined together would produce the four sided prism(7).

Mrs B. The SECOND of the primitive forms is the *tetrahedron;* which is a figure, as you know, with four triangular sides, all the triangles being equilateral. (Fig. 4, 5, and 6.)

TETRAHEDRON.

Seen from the top.

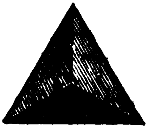

Fig. 4.

Side view.

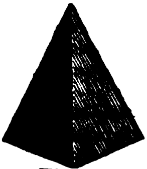

Fig. 5.

Outline showing the four sides.

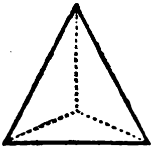

Fig. 6.

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5. What is the difference between *primary* and *secondary* forms?
6. What number of forms are generally considered as primary? What is the first form, and what are its varieties?

The THIRD is the *octahedron*, which, as its name indicates, is a figure with eight sides, and may be considered as consisting of two four-sided pyramids joined together at their bases. (Fig. 7 and 8).

The FOURTH, the *hexangular*, or six-sided prism, (Fig 9 and 10); of which nitre and rock crystal may furnish examples(8).

Octahedron.

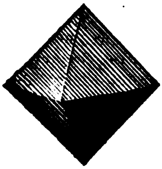

Fig. 7.

The same in outline.

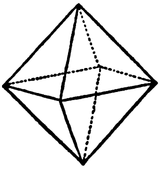

Fig. 8.

Hexangular prism.

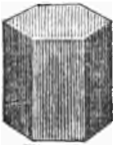

Fig. 9.

The same in outline.

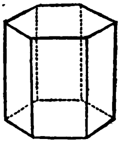

Fig. 10.

The FIFTH, the *rhombic dodecahedron*, (Fig. 11 and 12); a figure with twelve sides, each of which is a *rhomb.*

The SIXTH, the *dodecahedron with triangular faces*, (Fig. 13 and 14); which consists of two six-sided pyramids, united at their bases(9).

Rhombic Dodecahedron.

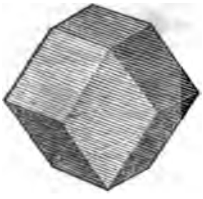

Fig. 11.

The same in outline.

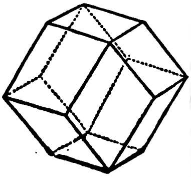

Fig. 12.

Dodecahedron with triangular faces.

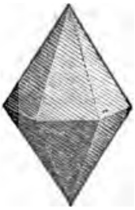

Fig. 13.

The same in outline.

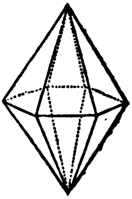

Fig. 14.

Caroline. It seems to me as though some of these six forms which you call *primitive* may themselves be composed, or built up, as it were, of others still more simple; yet the name *primitive* would seem to indicate that these were actually the most simple forms into which they could be reduced, either actually, or mathematically(10).

Mrs B. Such however is not the idea which the name is intended to convey. By the primitive form is meant that into which the crystal may, in general, be reduced by mechanical division, in a way to be presently explained. But it is capable of mathematical proof, that all these six primitive forms may be composed of three simple solids; the *tetahedron,* the simplest of pyramids; the *triangular prism,* the simplest of prisms; and the *parallelopipedon,* including the cube and rhomboid, the simplest of solids with parallel faces. (Fig. 15, 16, 17)(11).

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8. Give a description of the second third and fourth species.
9. Describe the two last of these primitive forms.
10. What observation is made concerning these primitive forms?
11. Into what simple solids may all these be reduced?

Tetrahedron.

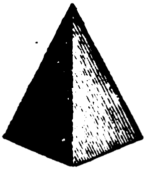

Fig. 15.

Triangular Prism.

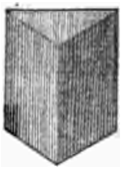

Fig. 16.

Parallelopipedon.

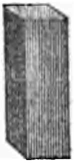

Fig. 17.

Hexangular Prism.

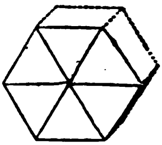

Fig. 18.

By drawing lines from angle to angle, across the centre of this hexangular prism, (fig. 18), it will be divided into equilateral triangles. It is plain therefore that this six-sided crystal might itself be composed of triangular prisms. In like manner a parallelopipedon would be produced by joining together, face to face, two only of the triangular prisms(12).

Emily. This is very satisfactory, and seems to accord with the general simplicity of the means by which nature operates. By what term are these simple forms designated, so as to distinguish them from the primary forms?

Mrs B. These have been called *integrant particles*, or *molecules.* When a single atom of an acid unites to an atom of any salifiable base, there will be produced by their combination an integrant, or individual atom of a salt. Thus an atom of carbonic acid may unite to an atom of lime, and the necessary result of this union will be the formation of an *integrant particle,* or single atom of carbonate of lime. Now it is plain that this integrant particle must possess some determinate form: it may itself be a rhomboid, or this figure may be produced by the junction of two of these integrant particles, thus giving rise to a primary crystal of carbonate of lime. By the accumulation of a large number of these, attaching themselves regularly to each other by the attraction of aggregation, a visible rhomboidal crystal must at length be produced. As a crystal so composed is, from its nature, incapable of being reduced into a more simple figure than the rhomboid, we should call it the primary form, which, in the case we have supposed, would be the same as that of the integrant molecule(13).

Caroline. The atomic theory has rendered us tolerably familiar with the idea of particles, which greatly aids us in this attempt to trace their mechanical arrangement; and this subject, which I thought would be rather uninteresting, is one that has already afforded me much satisfaction. I shall frequently amuse myself with tracing the forms which these integrant particles may produce by their combination. I fear however that I shall not be able from either of them to construct a *rhombic dodecahedron.*

Mrs B. Yet this may be derived from the cube, the most familiar of these integrant solids. The mode in which this may be done, will be clearly illustrated by means of this model. That integrant cubes may be built upon each other so as to form figures similar to themselves, and of any dimensions, you have already remarked. Now suppose these minute cubes to have produced a large cubical crystal: an examination of the model will show you how, upon this as a nucleus, other minute cubes may be so piled as to furnish a solid with twelve faces, each of which shall be a rhomboid(14).

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12. How might an hexangular prism be reduced into triangular prisms?

13. What is said respecting *integrant particles*, or molecules?

14. From what integrant particle may the *rhombic dodecahedron* be derived?

I have a number of other models which exhibit, with equal clearness, the production of many other secondary crystals; but as my design is merely to enable you to pursue the inquiry hereafter, I should rather embarrass than aid you by producing any other than the rhombic dodecahedron.

Formation of the Rhombic Dodecahedron from Integrant Cubes.

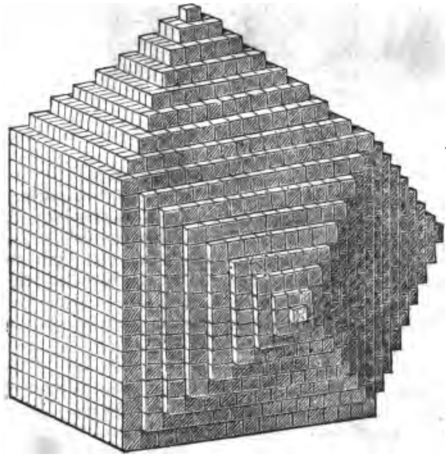

Fig. 19.

Emily. Your model renders the mode of forming such a crystal so clear as scarcely to require any explanation. After the cubical nucleus is formed, with its six regular faces, you suppose other integrant cubes to be piled upon each of them, but receding from the edge, by standing upon the second row of particles, and so continuing, by invisible steps, until a pyramid is formed. The model renders it quite evident that when this has been done upon two contiguous sides, a perfect rhombic face will be produced; and I plainly see that when all the sides have been so treated, a twelve-sided solid with rhombic faces will be the result of the arrangement(15).

Mrs B. Three of the faces on the cube are left, to show the original nucleus; and it will be readily conceived by you, that instead of receding from the edges by a single row of particles, the new layers may be placed two, three, or more rows back, and thus a great variety of other forms may be obtained, which, on a cursory examination, may not appear to be related to the one which we have examined, although derived from the same root(16). It is in consequence of such arrangements, that we find in nature that variety of crystals of the same substance which constitutes the *secondary forms.* These four models will still further exemplify the production of secondary forms. The first (fig. 20) exhibits a cube, the eight angular points of which are wanting, and are replaced by triangular faces. The second (fig. 21) shows the effect produced, when instead of the angular points, the edges are wanting. The third and fourth (fig. 22 and 23) exemplify the same facts in relation to the octahedron(17).

---

15. Describe the mode of producing it from cubes.
16. By what arrangement may they produce other crystals?
17. How is this exemplified by fig. 20, 21, 22 and 23?

Caroline. If I am not mistaken, the cube (fig. 20) would be converted into an octahedron, and the octahedron (fig. 22) into a cube, by continuing to slice off the angles, which are wanting in the models.

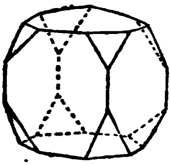
Fig. 20.

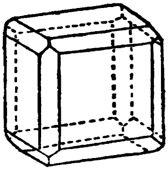
Fig. 21.

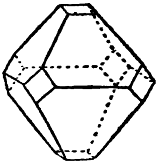
Fig. 22.

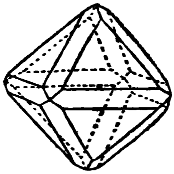
Fig. 23.

Mrs B. You are not mistaken, and the correctness of your remark must fully convince you how completely the primary and secondary forms may differ from each other, whilst they are, in fact, mathematically allied(18). A cubic crystal of fluate of lime may be readily reduced to an octahedron, by cutting off its angles, in the manner represented (fig. 20); and most other secondary crystals, may, in like manner, be made to exhibit their primitive forms. An attempt to cut them in any other direction would fail, and if persisted in would produce a common fracture, instead of a smooth regular surface(19).

Caroline. The different crystalline forms which bodies assume, seem, certainly, to justify the opinion that the integrant particles, or constituent atoms of matter, are various in their shape, and thus give rise to a variety of symmetrical figures in crystallized bodies; but for this I should have retained the idea, which, I believe, very generally prevails, that they are all spherical.

Emily. And perhaps they are so; for, certainly, symmetrical figures may be produced by spheres, as well as by triangular prisms and rhomboids. Do you not recollect how we admired the different forms in which the balls were piled at the arsenal? Why may not the various forms of crystals be, in like manner, produced by the accumulation of round particles(20)?

Mrs B. The opinion that the constituent particles of matter are either perfect spheres or spheroids, has been sustained by one of the first philosophers of the age, Dr Wollaston, whose name has been before mentioned to you. It is a fact that some of the crystalline forms are but imperfectly accounted for, upon the supposition of their being derived from the three integrant particles; there being secondary forms which they cannot produce without leaving spaces between them; that is, they could not every where touch each other by their flat sides(21).

Caroline. I am not a little pleased to find that I may return to the spheres in such good company. The balls at the arsenal, as Emily observes, seem to lend a powerful support to the theory of round particles.

Mrs B. I have some models of crystals supposed to be formed in this way, and which you have not yet seen. They are made simply of small leaden shot, cemented together by gum-water. The first (fig. 24) is the simplest mode of combining such balls, a combination in which they form an equilateral triangle.

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18. To what form could fig. 20 and 22 be thus reduced?

19. What is remarked respecting a cubical crystal of fluate of lime, and other secondary crystals?

20. What observations are made respecting the form of integrant particles?

21. What theory did Dr Wollaston advance respecting them?

Equilateral Triangle.

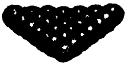

Fig. 24.

Tetrahedron.

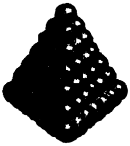

Fig. 25.

Triangular Prism.

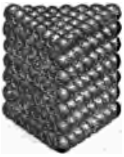

Fig. 26.

Parallelopiped.

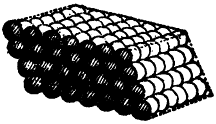

Fig. 27.

If between these, others are piled, the form of a triangular pyramid, or *tetrahedron* (fig. 25) will be produced. A number of the equilateral triangles (fig. 24) placed directly upon each other, supplies us with the triangular prism (fig. 26). The parallelopiped (fig. 27) is readily produced, as you see, by the arrangement shown in this model(22).

Emily. We have now all the *integrant molecules*, and from these, of course, all the *primary* and *secondary forms* may proceed, just as in the former instance.

Mrs B. In order to remove the difficulty in making up certain existing forms by perfect spheres, Wollaston supposed, as I have already intimated, that the constituent atoms of some species of matter are spheroidal, that is, not perfect spheres(23). This, like every thing relating to ultimate particles, is evidently hypothetical; and if hypothesis is ever to be admitted, it must be in such a case, where, from our limited power of perception, it is impossible that we should arrive at absolute certainty(24).

Caroline. Since then, on such a subject, you do not interdict hypotheses altogether, I may be still allowed to suppose that the constituent atoms of matter may be spheres; that these may combine together so as to form the integrant molecules; and that the integrant molecules may then arrange themselves exactly as was imagined in the first instance.

Mrs B. Such a conjecture is not only admissible, but has as much, at least, of probability on its side, as any other theoretical opinion, upon this subject, which has been proposed.

Although you can now deduce all the different crystals from the accumulation of spheres, yet as I have three other models prepared, which exhibit three of the primary forms, you will undoubtedly like to examine them. Here, (fig. 28) we have the perfect cube; the next (fig. 29) has the shot so piled on each side of a square as to complete the octahedron; whilst the third (fig. 30) gives you the hexangular or six-sided prism(25).

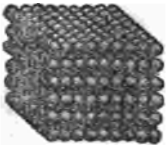

Fig. 28.

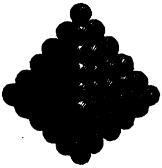

Fig. 29.

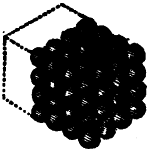

Fig. 30.

Emily. I am, of course, aware that the integrant molecules of a crystal

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22. What are fig. 24, 25, 26 and 27 intended to illustrate?
23. What is required to remove some difficulties in this theory?
24. What renders hypothesis admissible in such a case?
25. What is represented by fig. 28, 29 and 30?

are too minute to become objects of vision, and that whether particles be round or square, they may retire from each other, in steps, as it were, and yet present surfaces apparently unbroken(26); but is not such a structure sometimes rendered visible by the aggregation of larger particles than usually go to the formation of a crystal?

Mrs B. Such is actually the fact: these minute steps are not unfrequently exhibited on certain crystals, and I have some among my minerals in which they are quite observable(27).

We have now concluded our examination of those substances which belong to the mineral kingdom. In our next conversation we shall commence with those more complex beings which belong to the animal and vegetable creation, the consideration of which will complete our chemical course.

Caroline. I had hoped, my dear Mrs B. that in some part of our conversations you would have favoured us with an explanation of the nature of the steam engine. But I suppose that the consideration of this subject belongs rather to natural philosophy than to chemistry.

Mrs B. It is difficult to say to which department of science we are most indebted for the high degree of perfection to which this machine has been brought within the last age. It was not introduced to you in our conversations on natural philosophy, because without an intimate knowledge of the nature of steam, and particularly of the doctrine of latent heat, the operation of the steam engine can be but very imperfectly understood. But if it is your wish, we will devote our next meeting to an examination of the structure and action of this wonderful instrument.

Emily. We shall indeed be most gratified to do so, and shall welcome the hour which is to afford us some insight into a subject so interesting, and respecting which we are now completely in the dark.

CONVERSATION XXVII.

ON THE STEAM ENGINE.

Steam used to produce Motion by Hero of Greece. Mr Watt, the greatest improver of the Steam Engine. Admission of Steam alternately above and below a Piston in a Cylinder. The Steam Pipe, Eduction Pipe, Condenser, and Air Pump. Low Pressure Engine. Mode of setting an Engine to work. Rotary produced by a Vibratory Motion. Safety Valve. Atmospheric Engine. Watt's Engine. Fly Wheel. Parallel Motion. Nature of the High Pressure Engine.

Mrs B. The history of the steam engine, from the first rude attempts to communicate motion by the elastic force of vapour, to the almost intellectual action of this powerful machine, as now employed, is one which you may hereafter examine with much pleasure and advantage. Like the ship, the clock, the watch, and all other complicated machines, it has advanced by successive steps to the state of perfection which it has now attained.

Man could not apply fire to the purpose of heating water without having his attention, in some degree, arrested by the elastic force of steam. It is known that among the Greeks, Hero of Alexandria caused a wheel to revolve by the reaction of steam, issuing from boiling water. The useful application of this agent, however, is altogether of modern origin(1).

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26. Why may a surface formed of spheres appear perfectly even?
27. What is sometimes apparent in the structure of a crystal?
1. What is observed respecting the invention of the steam engine?

Emily. Then its history must be more perfectly known than that of the more ancient instruments; and the names of those who have successively improved it are not lost with the records of antiquity, but are registered in the list of public benefactors.

Mrs B. Your remarks are correct. Our business to day, however, will not be to learn the history of the steam engine, but to examine it in its present improved form; and should I succeed in making you acquainted with its structure, you will find no difficulty in understanding the various changes through which it had previously passed. The engine which I shall describe is called Watt's engine, as it is to Mr Watt, of England, that we are indebted for its most valuable improvements. In our examination of the steam engine it will be necessary to recur to what you have learnt, both in your natural philosophy and your chemistry, respecting the nature of heat, and of the elastic fluids: you must particularly observe the distinction which subsists between the vapours and the gases.

Caroline. We know that the vapours, by being cooled, may be converted into liquids; whilst the gases by any ordinary reduction of temperature will be merely diminished in bulk, still remaining in the aeriform state(2).

Mrs B. What, therefore, would be the effect of cooling a vessel which was filled with steam, and closed so that air could not find admission into it?

Emily. In this case the steam would be condensed, would assume a liquid form, and a vacuum would be produced within the vessel.

Caroline. Yes, and then, if the vessel was not of considerable strength, it would be crushed in, by the pressure of the atmosphere, like the square bottles which were broken when the air they contained was exhausted by means of the air pump(3).

Mrs B. The facts of the elasticity of steam, and its condensation by cooling, include the elements of motion in the steam engine, as improved by Mr Watt. This engine, unlike its predecessors, acts independently of the pressure of the atmosphere; as, in lieu of this pressure, Watt substituted the elastic force of steam, which, at the ordinary temperature of boiling water, is equal to that of the atmosphere, and this, you know, is about fifteen pounds upon every inch of surface(4).

Emily. The mechanical power of steam must necessarily be equal to that of the atmosphere; for when water boils in an open vessel, it must overcome the weight which is pressing upon it, and to do this, must exert a force equal to that by which its own power is resisted(5).

Mrs B. With the knowledge of this law, you will find no other difficulty in understanding the action of the steam engine, than that which arises from the necessary complexity of its mechanical arrangements. These are principally intended to regulate the admission of steam into it, from the boiler, and the discharge of this steam after it has performed its office(6).

I have made some diagrams, to aid us in explaining the operation of the engine, and you would find these drawings answer the purpose better than the machine itself, if we had one at our command.

Caroline. Undoubtedly; for by them you will be able to show us its interior structure, which we could not see in the real engine.

Mrs B. When steam is employed for the purpose of pumping water,

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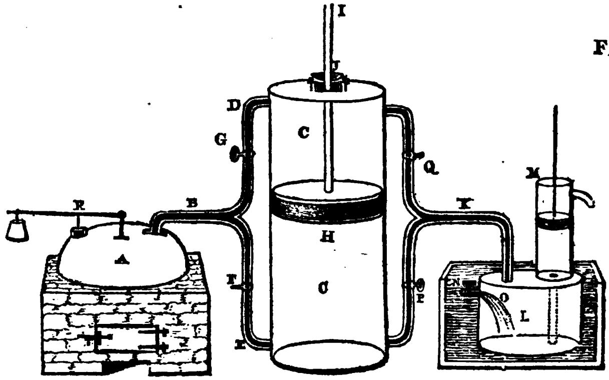
2, Repeat the distinction which subsists between gases and vapours.
3. What would be the effect of cooling a vessel containing steam?
4. What are the leading characteristics of Mr Watt's engine?
5. What proves the elastic force of air and steam to be equal?
6. What are many of the moving parts of the engine intended to regulate?

of propelling a boat, or of driving the machinery used in manufactories, it is admitted from a boiler into a cylinder, in which it operates upon a piston. The cylinder and piston are, in form, very similar to those of the common air or water pump. The piston, however, is without a valve(7).

This drawing represents such a piston within its cylinder. It is fitted to the cylinder so perfectly, that when it is worked up and down, no steam can pass between them. The drawing also shows the manner in which the steam is to be admitted and discharged, in order to operate upon the piston.

Steam Cylinder, Boiler, and Condenser.

Fig. 1.



I need not explain to you the design of that part which in the drawing is marked A.

Caroline. It is evidently the boiler, and the furnace for converting the water which it contains into steam.

Mrs B. And you perceive that a pipe, B, leads from this boiler, and branches off, so as to communicate with the upper part of the cylinder C, C, at the point D, and with the lower part at the point E. The communication with either the upper or the lower part of the cylinder may be opened or closed at pleasure, by means of the keys or valves, F and G(8).

Emily. There is no difficulty in perceiving that when F is closed and G open, the steam will be admitted above the piston only; but I should apprehend that if the piston, H, is to move up and down, and the piston rod I to pass freely through the top of the cylinder, the steam must escape around the piston rod, into the atmosphere.

Mrs B. The piston rod is made perfectly cylindrical, and is kept steam tight, at J, by passing through what is called a *stuffing box;* that is, a box, or opening, stuffed with tow, wool, or some other elastic substance. The rod is thus enabled to work freely, whilst the escape of steam is effectually prevented(9).

Caroline. When the steam is admitted at D, it is of course intended to force the piston down; but if the power of the steam is only equal to that

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7. Within, and upon, what does the steam first operate?
8. How is the steam admitted either above or below the piston?
9. How is the escape of steam around the piston rod prevented?

of the pressure of the atmosphere, the air below the piston must effectually prevent its descent(10).

Mrs B. That certainly would be the case, if means had not been devised to remove the air, and to obtain a vacuum under the piston. If this can be effected, the pressure of the steam must cause the piston to descend, and that with a power proportioned to its area or surface.

Emily. Its tendency to descend must in that case be very great indeed, as it will be equal to a weight of fifteen pounds upon every square inch of it. If the cylinder is large, this power must be enormous in amount(11).

Mrs B. You may conceive some idea of this force, when you are informed, that it surpasses the weight of a column of lead three feet in height, and of the same diameter with the cylinder, or piston, of the engine(12).

The mode by which a vacuum is created in the cylinder, was invented by Mr Watt, and is one of the most important of his many improvements. You perceive that in the drawing there is a branched tube, similar to that which is connected with the boiler, but on the opposite side of the cylinder, and that it terminates in a vessel marked L. The first tube, B, is called the *steam pipe*, as it conducts the steam into the cylinder; the latter is named the *eduction pipe*, and is intended for the discharge of the steam, after it has acted upon the piston(13). The vessel L, into which the steam is conveyed by the eduction, or discharge pipe, is called the *condenser;* it is a strong metallic box, so enclosed that no air can enter it(14).

Caroline. And I am not wise enough to tell why the steam should enter it, for, unless a vacuum could be maintained there, the steam would be no more inclined to pass into it, than to remain in the cylinder; and if it did pass into it and become condensed there, this condenser, after a while, would be filled with water. These are difficulties which would place all my skill at defiance; but the philosopher who invented this apparatus has, of course, provided against them(15).

Mrs B. The small pump M, which is placed upon the condenser, removes these difficulties completely. It is kept constantly at work, and exhausts the condenser, both of air and of water; and thus produces and maintains a vacuum, the necessity of which you have had the good sense to foresee. This pump is technically called the *air pump.* It does not differ from the common pump, excepting in the accuracy with which it is made(16).

Caroline. I wonder that I had not understanding enough to perceive the use of it, in the conspicuous situation which it occupies.

Emily. Does not the heat which the steam carries with it into the condenser, interfere with the condensation; or rather, I should ask, in what way is this interference prevented?

Mrs B. Just as it is prevented in the common still, the worm of which is kept surrounded by cold water. The condenser stands in a cistern, or vessel N, called the *cold water well.* On board of steam boats this *well* is supplied by the water of the river, and on land from any convenient source. To render the condensation still more rapid, a stream of cold water, O, is allowed to run from the well into the condenser(17).

Caroline. The air pump, then, must be sufficiently large to pump out

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10. If the piston had air on one side and steam on the other, what would be the result?
11. What if steam was on one side and a vacuum on the other?
12. To the weight of what mass of lead would this power be equal?
13. What are the *steam* and *eduction pipes* intended to effect?
14. What kind of vessel is that which is called the *condenser?*
15. What is necessary to cause the steam to pass into it?
16 What are the situation and use of the *air-pump?*
17. In what way is the steam condensed in the condenser?

the air, the water which runs in from the cold water well, and that which is produced by the condensation of the steam. By what means is this air-pump kept continually at work?

Mrs B. The air pump and all the other moving parts of the engine are acted upon by the engine itself, and of course some portion of its power is expended in working them(18). This will be better understood by you after I have shown and explained to you a more perfect drawing of the whole engine. Our present sketch, however, will enable you to trace the action of the engine more readily than the complex figure necessary to show its general structure.

Emily. You have so clearly explained the use of the condenser, that with a little study, we might almost venture to trace the operation of the engine, without further aid; but whilst we have you for a guide, we have not the temerity to venture alone along a path which we have never explored.

Mrs B. We have now advanced sufficiently far to set our engine at work, at least in imagination. The kind of machine which I am describing to you, is sometimes called the *double acting engine.* It is so named because the piston is forced upwards, with the same power with which it is made to descend. The steam, as I have before intimated, being alternately admitted to, and removed from, each side of it.

You perceive that the eduction pipe, K, may allow of a communication between the condenser, and either end of the cylinder, accordingly as the vents, or valves, at P and Q, are opened or closed. These vents we will hereafter simply call valves, as they actually are such in the working engine. Suppose now that the whole four valves, F, G, and P, Q, were opened at the same time, whilst the water in A was kept boiling, what would be the result?

Emily. The steam would then rush into the cylinder at both ends, and press equally on each side of the piston; and from the cylinder it would pass through both branches of the eduction pipe into the condenser.

Mrs B. Yes; and it would pass up from the condenser through the valves of the air-pump, blowing out the air before it and occupying its place(19). This is in fact the first step taken when such an engine is to be set at work; and this operation is called *blowing through*(20). After blowing through, that is, filling the whole interior of the engine with steam, can you tell me what would be the consequence of closing the valves F and Q?

Caroline. Allow me to consider a moment. The steam would continue to enter through the valve G, into the upper part of the cylinder, where it would be confined by the closing of the valve Q. I suppose, too, that the valve P being open, and the valve F shut, the steam would rush from under the piston, into the condenser, where it would be converted into water; this would necessarily produce a vacuum under the cylinder, and the piston would be forced down(21).

Mrs B. Perfectly well explained. After understanding how the piston and its rod are forced down, you will find little difficulty in perceiving how they may be elevated by the same means, and with a power equal to that of their descent. Only suppose the valves F and Q to be opened, and P and G to be closed; and you perceive that the steam would then be admitted under the piston, whilst that which had forced it down would rush through the valve Q, into the condenser, and cause a vacuum to be instantly formed above the piston. Thus situated, it would be carried to the top of the cylinder by the elasticity of the steam, and when there, if the open valves are again

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18. What is said of the means of giving motion to the air-pump?
19. What would be the effect of opening all the valves?
20. What is this operation denominated?
21. Explain the steps necessary to set the engine in motion?

closed, and the closed valves opened, it will again descend with equal power(22).

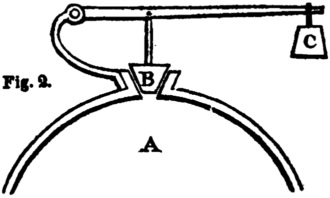
Emily. I had entertained the idea that the operation of the engine was in some way connected with the pressure of the atmosphere, but I now perceive that the effect of this pressure must always be to retard its action, and that it would actually stop, if more air entered than the air pump could exhaust(23).

Caroline. The passing of the piston up and down I now perfectly understand, but still I do not perceive how this is to propel boats, drive carriages, pump water, and turn almost all kinds of machinery. I thought that the force of the steam effected all this; but we seem to have destroyed the steam in the very act of moving the piston and its rod up and down.

Mrs B. And to produce this motion of the piston is all that is required of it. If you will supply the machinist with powerful motion of any kind, he well knows how to give to it such a direction as shall serve all his purposes. Do you not perceive that if the piston rod was attached to the end of the handle of a pump it would cause it to vibrate, as a man does, when he uses it for the purpose of raising water? If a rotary motion is required, it can be obtained from the vibration of the piston rod, just as the wheel for spinning flax is made to revolve through the medium of a crank, by merely raising and lowering the foot(24).

Emily. I confess that I also was impressed with an idea that the force of steam was applied in some way more direct than that which you have described. I now perceive, however, that it is merely a substitute for the power of men or horses, and that it acts, as they generally do, through the intermedium of levers and wheels.

Caroline. The part marked R, which, I believe, is called the safety valve, you have not described. I have always conceived this to be one of the most important appendages to the steam engine.



Safety Valve.

Fig. 2.

Mrs B. And so it is, as its name indicates. With the nature of valves, generally, you are acquainted, and know that they are of different forms. The safety valve is in form similar to the stopper of a decanter, but more conical. This is a separate drawing of it, in which A shows the upper part of the boiler, and B the valve. You will perceive from the drawing that if the steam within the boiler A becomes very elastic, it will press upon the lower end of the valve B, and if the weight C, which tends to keep it down, is not too great, it will be raised, and the steam escape, without endangering the boiler(25).

Emily. In the low pressure engine, the weight, I suppose, is equal to fifteen pounds upon each square inch of the lower end of the valve, so that its force may amount to the same as that of the atmosphere.

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22. By what means is the piston made to ascend?
23. What effect would the admission of air produce?
24. How does the engine operate in moving other machinery?
25. Describe the structure and operation of the safety valve.

Mrs B. By no means. The atmosphere itself has this force, and an additional weight of fifteen pounds upon every inch would resist the pressure of the steam until it became equal to that of two atmospheres. The weight upon each square inch of the valve should not exceed three or four pounds; but this amount is necessary in order to give to the steam a degree of elasticity sufficient to blow out against the atmosphere, with such a force as completely to counteract its tendency to pass into the engine(26.)

Emily. Was there not a machine called the *Atmospheric Engine* which was in use before the improvements made by Mr Watt?

Mrs B. Yes: and it was a desire to improve the operation of this engine, that led Mr. Watt to the adoption of those devices by which he has furnished us with a power so efficient and so manageable. The *Atmospheric Engine* was invented, in England, about the commencement of the last century by Newcomen. He used a cylinder and a piston, but the whole motive power of his machine was derived from the pressure of the atmosphere(27).

Caroline. Then I think it could not with much propriety be called a steam engine.

Mrs B. It was as truly a steam engine as those now in use. Steam was employed in it to create a vacuum, without which the pressure of the atmosphere could not have been rendered efficient. In Newcomen's engine there was a boiler, and a steam pipe leading from it into the lower part of a cylinder, somewhat in the manner of the lower pipe E, in our first drawing. The upper part of the cylinder was not closed, but the air was freely admitted to press upon the surface of the piston(28). On turning again to the drawing, you may suppose the piston H to be at the bottom of the cylinder C, C, and to fit it air tight; can you tell me what force, besides the weight of the piston itself, would be required to raise it in the cylinder, provided neither air or steam were admitted below it?

Emily. In that case the whole weight of the atmosphere must be lifted, as there would be a vacuum beneath the piston. The power, therefore, must be proportioned to the diameter, or area, of the piston(29).

Mrs B. But were we to admit steam under the piston, from the boiler A, would this difficulty exist?

Emily. Certainly not; because the steam, by its elasticity, would be a counterpoise to the weight of the atmosphere. The piston might then be readily raised to the top, as the cylinder would be filled with steam(30).

Caroline. Yes, and if this steam was then condensed, there would be a vacuum, into which the piston would be forced by the weight of the air.

Mrs B. By applying cold water to the cylinder, the steam within it would be condensed; and this was done in Newcomen's engine at every stroke of the piston(31). This instrument, although very useful, was also very defective; but as my whole design was to give you some idea of the way in which the pressure of the atmosphere was employed in it, I shall not at present take any further notice either of its merits or its defects.

Caroline. Some of the latter, at least, are very apparent. It must have wasted a great deal of steam in heating the cylinder at every stroke, and its power was exerted in one direction only(32).

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26. To what should the load upon the safety valve amount?
27. By whom, and at what period was the *atmospheric engine* invented?
28. What was the construction of the cylinder, and where was the steam admitted?
29. By what power would the raising of such a piston be opposed?
30. How would the admission of steam obviate this difficulty?
31. How was the pressure of the atmosphere made to operate?
32. What two defects are mentioned, as belonging to this engine?

Mrs B. You are now prepared to examine my drawing of a steam engine, with most of the working parts attached to it. You will find that some of them are arranged differently from those in our first sketch, as this larger drawing is a more perfect representation of the actual form of the engine as applied to use. But still you must not expect to find it an exact likeness of any one which you have seen. To every tube and valve I have assigned such a position as I thought would enable you most readily to understand it. On board of steam boats, and in manufactories, the parts are crowded together, and distorted in various ways, for the purpose of saving room, or of obtaining other advantages(33).

Caroline. Your first drawing has made the manner in which the steam operates so plain, that we cannot find any difficulty in following you in your further developments of this beautiful machinery.

Mrs B. You will, at the first glance, perceive the resemblance between this more full drawing (fig. 3) and the former, so far as the structure of the cylinder, and the operation of the steam are concerned. To all of its corresponding parts I have affixed the same letters. You will, therefore, readily trace their connexion.

Emily. The form itself is but little altered, but I perceive that at G, F, and P, Q, you have placed valves for the admission and discharge of the steam; and that they appear to be similar in shape to the safety valve upon the boiler.

Mrs B. They are of the same kind, and are called *puppet valves.* The casing which surrounds each of them is called a *steam box.* They are opened and closed by means of a small rod passing through a stuffing box, like that surrounding the piston rod. You perceive the loops upon the tops of each of these rods; by these they are raised and lowered. This is effected, at the moment required, by apparatus worked by the engine itself(34).

Emily. The part S, which I know is called the *lever* or *beam*, is made to vibrate by means of the piston rod, the upper end of which is attached to it. What is the particular end answered by this large lever?

Mrs B. The intention of this lever is to communicate the motion generated in the cylinder, to any machinery which is to be operated upon. Thus if it is designed to raise water from a well or from a mine, a piston rod, T, may be attached to the opposite end of the lever, and made to work a pump below it. I have not drawn the pump, as you are well acquainted with its structure, and I have avoided multiplying parts unnecessarily(35).

Caroline. In this case the lever becomes the pump handle and the engine the power which works it. This removes all the mystery about applying steam to the raising of water.

Mrs B. When a rotary motion is required, as in the paddle wheels of steam boats, and in mills of most kinds, it is obtained from that of the *fly wheel* V: this is caused to revolve by the action of the rod W, which acts upon the crank X. A wheel of this description, or something which answers a similar purpose, is attached to all steam engines, and to many other machines, in order to regulate their motion. In large engines, the fly wheel may weigh several tons, and this great weight is absolutely necessary to their steady and uniform action(36).

Emily. But does not this waste a considerable part of the power of the engine? It must require no little force to move so heavy a wheel.

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33. What is said respecting the drawing and the actual engine?
34. What is said of the valves in the steam and eduction pipes?
35. What is the purpose answered by the *lever-beam?*
36. What is remarked respecting a rotary motion and *fly wheel?*

DESCRIPTION

OF

WATT'S LOW PRESSURE STEAM ENGINE.

A. The BOILER, the dark part representing steam.
B. The STEAM or INDUCTION PIPE, conducting steam into the cylinder.
C. The CYLINDER, communicating with the boiler both above and below.
D. The branch of the steam pipe opening into the upper end of the cylinder.
E. The branch opening into the lower end.
F. The LOWER STEAM VALVE, represented as open.
G. The UPPER STEAM VALVE, represented as closed.
H. The PISTON, which is operated upon by the steam on each side alternately, causing the motion of the piston rod and the lever beam.
I. The PISTON ROD, attached to the piston, and to the beam.
J. The STUFFING BOX, through which the piston rod works steam tight.
K. The EDUCTION, or DISCHARGE PIPE, by which the steam is conveyed into the condenser, after it has performed its office in the cylinder.
L. The CONDENSER, surrounded by the cold water well.
M. The AIR PUMP, to keep the condenser exhausted of air and water.
N. The COLD WATER WELL, which must be constantly supplied with fresh water.
O. A stream of water, running from the well into the condenser.
P. The LOWER VALVE OF THE EDUCTION PIPE, represented as closed.
Q. The UPPER EDUCTION VALVE, represented as open.
R. The SAFETY VALVE, with its lever and weight.
S. The LEVER BEAM, caused to vibrate by the piston rod.
T A PUMP ROD, which may be attached to a pump for raising water from a well or mine.
V. The FLY WHEEL, which serves to equalize and regulate the motion.
W. The CRANK ROD, or SHACKLE BAR, serving to give motion to the fly wheel.
X. The CRANK, acted upon by the rod and lever beam.
Y. COCKS to ascertain the height of the water in the boiler.
Z Z. Jointed levers which form the PARALLEL MOTION.

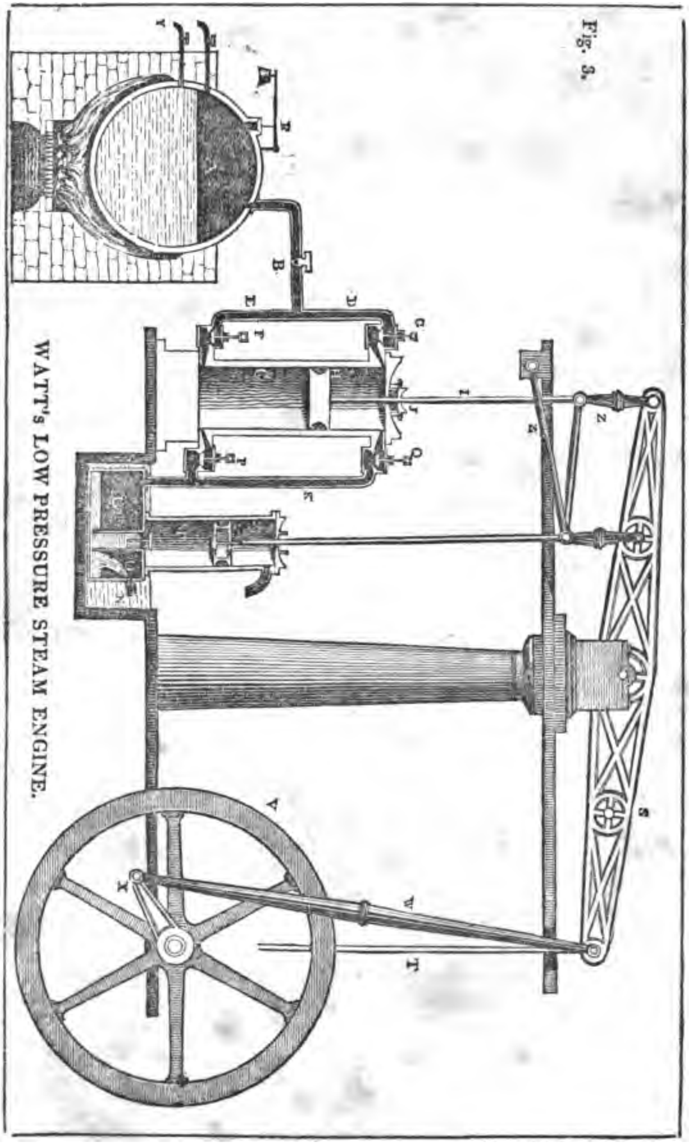

Fig. 3.

WATT's LOW PRESSURE STEAM ENGINE.

Mrs B. The loss of power is but trifling, amounting to little more than the friction of the axle; for the wheel, by its momentum, gives back again the power which it receives, whilst it prevents that jerking from the vibration of the piston and the beam, which would otherwise soon destroy the engine.

Caroline. The piston rods, both of the cylinder and of the air-pump, are attached to jointed levers, and through them to the beam. I have heard these jointed levers called the parallel motion; will you be good enough to describe to us their nature and use?

Mrs B. This *parallel motion* was a most happy contrivance of Mr Watt. You perceive that as the piston rods pass through a stuffing box in the caps of the cylinder, they require to be carried up and down vertically. The end of the lever vibrates in a curve, and would therefore give to the piston rods a rocking motion, which must bend or break them: this the parallel motion prevents(37). I have made a sketch which will serve to show you the principle upon which it acts—here it is.

The Parallel Motion.

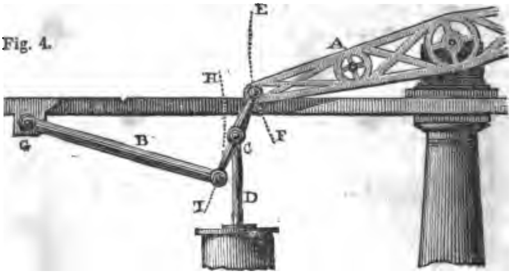
Fig. 4.

In this drawing, A is one end of the lever of the engine, which is connected to a second lever B, by means of a jointed piece C, to the middle of which jointed piece the piston rod is attached.

Emily. That is very simple and beautiful. I see plainly how it operates. As the main lever A draws one end of the connecting joint C in the curve E F, the lever B, which is attached to the building at G, draws the opposite end of it in the reverse curve H I, the consequence of which is, that the middle of the piece C, to which the piston rod is attached, passes up and down in a vertical line(38).

Mrs B. There are several other equally ingenious appendages to the steam engine. One of these is called a *governor*, as it is intended to govern the velocity of the engine's motion. When the engine begins to move too rapidly, the governor acts upon a valve which lessens the aperture by which the steam is admitted, and this diminishes the cause of motion(39).

Levers, which are raised up and depressed by what is called an *eccentric*, which is affixed to the shaft of the fly wheel, are now employed to open and close the valves in the steam and the eduction pipes. I cannot, however, explain all these to you at present, as it would detain us too long from our chemistry(40).

Caroline. You have explained enough to interest us very highly in the subject; and if, without too much sacrifice of time, you could inform us in

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37. For what purpose is the *parallel motion* used?
38. Describe the structure and operation of this part of the engine?
39. What is the design of the part called a *governor?*
40. What is said of the opening and closing of the valves?

what the high pressure engine differs from that which you have described, it would gratify us very much.

Mrs B. I will do so with pleasure; it is a point, indeed, which must not be altogether omitted, although I can give you but a mere outline.

You are aware that when water is confined in a close vessel, its temperature may be increased above the ordinary boiling point, and that the force of its vapour will be proportionably increased.

Caroline. That we understand very well, and know that it may be so heated that scarcely any vessel, however strong, can resist its force(41).

Mrs B. Suppose that in Mr Watt's engine you were to omit the cold water well, the condenser, and the air pump; what then would become of the steam, when either of the valves P or Q was opened?

Emily. In that case the steam would blow off into the atmosphere at every stroke of the engine. But so situated I do not see how the engine could continue to work, because the atmosphere would be admitted into the cylinder, and counteract the pressure of the steam on the opposite side of the piston(42).

Mrs B. But if the boiler was made sufficiently strong, and the water so highly heated that its vapour operated with a power equal to that of five atmospheres, or seventy-five pounds upon the square inch, what would then be the consequence?

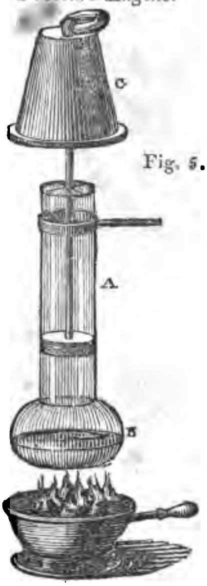
Illustration of the Low Pressure Engine.

Fig. 5.

Emily. In that case the excess of the pressure of the steam over that of the air would be sixty pounds upon every square inch, and the engine would work with great power, and certainly it might then be made much smaller than the low pressure engine, and yet have equal power(43).

Caroline. But still there would be the loss of a whole atmosphere which the condenser and air pump would save.

Mrs B. The air pump, you must recollect, not only saves, but also expends power, as it requires considerable force to work it; whilst it also renders the engine much more complex and expensive. The engines used upon rail roads are all of the high pressure kind, as they could not carry with them a supply of cold water to condense their steam; and they usually work with a pressure as great as that of which I have spoken(44).

I have here an instrument by which you can see the effects of elastic steam in overcoming the pressure of two atmospheres. It is not safe to carry the experiment beyond this, as the vessel which I use is of glass.

Caroline. I should have apprehended some danger of bursting it even with the power of which you speak.

Mrs B. I have repeatedly tried it, without accident, and do not doubt its capacity to raise a still greater weight.

The glass tube, or cylinder, A, has an area of about

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41. What is the effect of confining water, and heating it highly?
42. What would be the effect of removing the condenser?
43. Suppose the steam to be equal in its pressure to five atmospheres, with what power would it act in the high pressure engine?
44. For what purpose are these engines peculiarly adapted?

an inch. A piston fits closely in it, and the bottom part, B, is made globular, and contains water. On the top of the piston I have placed a weight, C, of fifteen pounds, which added to that of the air will exact a power of thirty pounds in order to raise the piston.

I will now place the bulb over the chaffing dish of coals, and allow it to remain until you see the weight forced up by the steam(45).

Caroline. Will it be necessary to double the temperature of the water in order to double the elasticity of the steam?

Mrs B. By no means; it only requires an elevation of temperature of between thirty and forty degrees to double the elasticity of the vapour from boiling water. The elasticity will be again doubled by a similar increase of temperature, and will be equal to four atmospheres before it arrives at 300°(46).

Emily. See, Caroline, the piston is now rising with the heavy weight upon it. That is a very satisfactory experiment; and the more remarkable as being performed in so fragile a vessel as one of glass.

Mrs B. It is now time to adjourn for the evening; and you must not permit your thoughts upon steam to drive from your recollection that when we next meet, our subject is to be organic chemistry.

CONVERSATION XXVIII.

ON ORGANIZED BODIES, AND VEGETABLE CHEMISTRY.

Organs of Animals and Vegetables. Composition of Organic Substances. Chemical Affinity controlled by Vitality. Destructive Distillation, and Spontaneous Decomposition. Proximate and Remote Principles. Vegetable Principles divided into three classes. List of some of them. Vegetable Acids,—Oxalic, Tartaric, Citric, Benzoic, Gallic, &c. Formation of Ink. Vegetable Alkalies; Morphia and Narcotine; Quinia and Cinchonia. Oils, Fixed, Drying, Volatile or Essential. Camphor. Resins. Varnishes. Amber. Caoutchouc or Gum-elastic. Wax. Bitumens. Naphtha. Petroleum. Mineral Tar. Pitcoal. Anthracite. Coke.

Mrs B. We have hitherto treated only of the simplest combinations of elementary substances, such as alkalies, earths, acids, salts, &c.; all of which belong to the mineral kingdom. It is time now to turn our attention to a more complicated class of compounds, that of ORGANIZED BODIES, which will furnish us with a new source of instruction and amusement.

Emily. By organized bodies, I suppose you mean the vegetable and animal creation. I have, however, but a very vague idea of the word *organization*, and I have often wished to know more precisely what it means.

Mrs B. Organized bodies are such as are endowed by nature with various parts, peculiarly constructed, and adapted to perform certain functions connected with life. Mineral compounds are formed by the simple effect of mechanical or chemical attraction, and may appear to be, in some measure, the productions of chance; but organized bodies bear the most striking and impressive marks of design, and are eminently distinguished by the possession of that unknown principle called *life;* a principle from which the various organs derive the power of exercising their respective functions(1).

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45. Describe the experiment showing the elastic force of steam.
46. What elevation of temperature doubles the elasticity of steam?
1. What are organs, and how are *organized bodies* distinguished?

Caroline. But in what manner does life enable these organs to perform their several functions?

Mrs B. That is a mystery which, it is most probable, the Creator never intended that we should be able to unfold. We must, therefore, content ourselves with examining the effects of this principle: as respects the cause, we have been able only to give it a name, without attaching any other meaning to it, than the vague and unsatisfactory idea of an unknown agent(2).

Caroline. And yet I think I can form a very correct idea of life.

Mrs B. Pray let me hear how you would define it.

Caroline. It is, perhaps, more easy to conceive than to express the idea:—let me consider—Is not life the power which enables both the animal and vegetable creation to perform the various functions which nature has assigned to them?

Mrs B. I have nothing to object to your definition; but you will allow me to observe, that you have only mentioned the effects which the unknown cause produces, without giving us any notion of the cause itself.

Emily. Yes, Caroline, you have told us what life *does*, but you have not told us what it *is*.

Mrs B. We may study its operations; but we should puzzle ourselves to no purpose by attempting to form an idea of its real nature.

The organized bodies, which constitute the animal and vegetable kingdoms, contain a vast number of different compounds, which are nearly all produced by the union of the same elementary principles. Vegetables consist essentially of *carbon, hydrogen* and *oxygen;* and the same substances, with the addition of *nitrogen,* are the principal constituents of the most important compounds found in the animal creation(3).

Caroline. But these are not the only substances existing in these bodies, as lime and potash and phosphorus have all been mentioned as procured from them.

Mrs B. To your list you might also add sulphur, iron, silex, and other substances contained in the soil, from which all organized beings primarily derive their nourishment. But although these are essential to certain parts of particular vegetables and animals, animalization and vegetation may, to a certain extent, exist without them(4).

The organs with which organized beings are endowed, select and arrange those constituent principles, and form them into the different kinds of juices and solids which constitute vegetable and animal substances, in all their varieties(5).

Emily. And are not these combinations always regulated by the laws of chemical attraction?

Mrs B. The organs of animals and of plants cannot, certainly, force principles to combine which have no attraction for each other; but yet they control the combinations which take place, by bringing these principles into contact in such proportions as will, by their chemical combination, form the various organic products, instead of uniting according to those laws of simple affinity which they would obey, if uninfluenced by these organs of vitality(6).

Caroline. We may then consider each of these organs as a curiously constructed apparatus, adapted to the performance of a particular chemical process.

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2. Are we in any degree acquainted with the *principle of life?*
3. What are the principal constituents of vegetable and animal substances?
4. What other materials do some of them contain?
5. What particular office do the living organs perform?
6. How far are the secretions under the influence of chemical affinity?

Mrs B. Exactly so. As long as the organized being lives and thrives, its constituents are presented to each other in such a way, that they are not susceptible of entering into other combinations; but no sooner does death take place, than this controlling power is destroyed, and new combinations are produced.

Emily. But why should death destroy the combinations which have been actually formed; the principles must remain in the same proportions, and consequently, I should suppose, in the same order of attractions?

Mrs B. You must remember, that both in the vegetable and animal kingdom, it is by the principle of *life* that the organs are enabled to act. When deprived of that agent, or stimulus, their power ceases, and an order of attractions succeeds, similar to that which would take place in mineral, or unorganized matter(7).

Emily. It is this new order of attractions, then, that destroys the organization after death; for if the same combinations still continued to prevail, there would be no spontaneous decay, or putrefaction, but the being would always remain in the form possessed by it when it died.

Mrs B. And that, you know, is never the case; for although by drying, or other processes, it may be partially preserved for some time after death, yet, in the natural course of events, all bodies return to the state of simple elements, or form binary combinations, such as water, carbonic acid, carburetted hydrogen, &c. In this we see an admirable dispensation of Providence, by which those beings that have ceased to live, are rendered fit to enrich the soil, and become subservient to the nourishment of others(8).

Caroline. You have exhibited to us one of the compounds resulting from the exertion of those affinities which produce the spontaneous decomposition of a plant: I allude to the carburetted hydrogen, collected from the vegetable deposite at the bottom of a pond.

Mrs B. The prevailing tendency of the carbon and hydrogen which every plant contains, is to combine with so much oxygen as shall convert them into carbonic acid and water. These form a part of the new compounds evolved, in whatever way the decomposition of a vegetable may be effected. But in most vegetable principles, the quantity of oxygen contained is insufficient to saturate the hydrogen and carbon, and these latter principles, therefore, unite together, and produce the carburetted hydrogen(9).

Emily. I should suppose that vegetable substances would be incombustible, if the oxygen contained in them were sufficient to saturate their hydrogen and carbon; as in this case they would have no tendency to combine with the oxygen of the atmosphere(10).

Mrs B. Your conclusion is undoubtedly correct. When vegetables are burnt in the presence of oxygen, water and carbonic acid are almost the exclusive products; but when heated to redness in close vessels, the whole quantity of oxygen which they contain is, in many cases, employed in saturating a small part only of their hydrogen. It is in consequence of this circumstance that certain vegetable products, such as tar, rosin, and bituminous coal, are sometimes used at the gas works, for the production of the carburetted hydrogen with which some of our large cities are illuminated(11).

Emily. The odour given out in the burning of animal substances differs very much from that of vegetables; this difference must result from the pre-

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7. What occurs in these compounds when life ceases?
8. What useful purpose is accomplished by their disorganization?
9. What is the prevailing tendency of the constituents of vegetables, and what the actual products of their decomposition?
10. What would result if vegetables contained a large portion of oxygen?
11. What is the result when they are heated in close vessels?

sence of nitrogen, and the consequent production of principles not evolved from vegetables.

Mrs B. Certainly: this additional agent gives rise to new affinities, and of course, to the formation of new products; among which will be found both ammonia and cyanogen. There are a few vegetable substances which also contain nitrogen; and these may, in general, be distinguished by their producing, during their combustion, an odour similar to that given out by animal matter.

Caroline. This fourth constituent of animal matter may probably account for its greater tendency to decomposition; as when life is extinguished, the affinities, which are left free to operate, are more numerous than those which produce the disorganization of vegetables(12).

Mrs B. From what has been already remarked, you may perceive that the products of vegetation, and of animalization, are characterized by the following circumstances:—1st, by being composed essentially of the same elements;—2d, by the facility with which they undergo spontaneous decomposition;—3d, by the impracticability of forming them by chemical means; and 4th, by being decomposed at a red heat(13).

Emily. There must, undoubtedly, be a considerable difference between the products of decomposition when it takes place spontaneously, and when it is effected at the temperature of ignition.

Mrs B. It is very great; but even at the temperature of ignition, the presence or the absence of atmospheric air essentially influences the result(14). When organized substances are decomposed at a red heat in close vessels, the process is called *destructive distillation.* In this case, a large quantity of charcoal usually remains in the retort, which, had atmospheric air been present, would have been converted into carbonic acid. The volatile products, also, which escape, are not products of combustion. The formation of carburetted hydrogen, just now noticed, may serve to exemplify this fact.

Caroline. Certainly; for had air been present, the carburetted hydrogen would have combined with oxygen, and been converted into carbonic acid and water(15).

Mrs B. Air acts an important part also in the slow decomposition of organic matter; but its influence at common temperatures, and at that of ignition, must necessarily vary greatly. Under circumstances so different, the principles concerned will combine in proportions very dissimilar; and the extent to which the decomposition will be carried, must be equally varied(16).

Emily. The subject of *organic chemistry,* as it relates both to vegetables and to animals, seems very naturally to divide itself into two parts. I suppose you will call our attention to these separately.

Mrs B. Yes; and we shall first consider what is denominated VEGETABLE CHEMISTRY: from this department you will acquire a knowledge of the various principles obtained by the decomposition of plants(17).

Caroline. Such substances must be capable of undergoing two kinds of decomposition very different from each other. If, for example, we decompose a vegetable perfectly, we shall obtain from it nothing but oxygen, hydrogen, and carbon; and every kind of vegetable would yield exactly the same materials. But vegetables contain oils, and acids, and sugar, and gum, and juices of various kinds; the decomposition by which these are separated

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12. What is the effect of the nitrogen upon those substances which contain it?
13. What are the characteristics of the products of organization?
14. What is said of their decomposition at high temperatures?
15. What is *destructive distillation*, and what is said respecting it?
16. What is observed respecting the influence of the atmosphere?
17. What is intended by vegetable chemistry?

from each other, must be essentially different from the former kind of decomposition; as the substances obtained are themselves still capable of being separated into others more simple.

Mrs B. Your ideas upon this point are judicious and correct. A vegetable may be analyzed for the purpose of discovering what are the different compounds that have been formed in it during the period of its growth, and upon the chemical character of which its particular properties depend; and each of these principles may in its turn be analyzed in order to ascertain the proportionate quantities of oxygen, hydrogen, and carbon of which they respectively consist(18).

Those distinct compounds which exist ready formed in a plant, are called its PROXIMATE, or IMMEDIATE PRINCIPLES. Thus *sugar*, *starch*, and *gum* are *proximate principles*, and these we obtain by *proximate analysis*. When we decompose them, to ascertain how much they contain of each of the simple bodies, the operation is called *ultimate analysis*(19). This, however, is a process of great delicacy, as in attempting to obtain the proximate principles, we are in danger of decomposing them by the agents we employ; and in reducing them into their ultimate principles, the presence of air or of moisture may supply us with a portion of oxygen or of hydrogen, and thus lead us to a wrong estimate of the quantity of these substances contained in the article under examination(20).

Emily. The sap of plants, is, I suppose, one of their proximate principles, and as this can be obtained without using heat, or any other agent calculated to decompose it, there can be but little difficulty in ascertaining its properties.

Mrs B. The *sap* contained in vegetables is not to be considered as a single proximate principle, but as a very complex mixture of several of them in solution, together with the ingredients which the roots have sucked up from the soil, and from which the various organs of the plant secrete and appropriate those materials which are necessary to its nourishment, and to the formation of the stem, the leaves, the fruit, and all the other parts(21).

Caroline. In the ultimate analysis of plants I suppose that the sour juices of fruits, and other acid parts, are found to contain more oxygen than those which are either sweet, or bitter; as, from the composition of plants, oxygen must necessarily be their acidifying principle.

Mrs B. Such is the fact; and those parts which are the most eminently combustible, as the resins and oils, for example, abound more in hydrogen and carbon. We are indebted to those distinguished French chemists Gay-Lussac and Thenard, for some valuable researches upon this subject. From the ultimate analysis of a great number of vegetable compounds, these philosophers were led to divide the proximate principles of plants into three classes, depending upon the proportionate quantity of oxygen and hydrogen contained in each(22). Those ingredients may exist in such compounds, in the same proportions in which they do in water, or there may be an excess of either of them. The *first* class embraces those substances in which there is more than a sufficient quantity of oxygen to convert all the hydrogen into water: to this belong the *vegetable acids*. The second class contains those in which there is more hydrogen than is sufficient to combine with the oxygen in the production of water: these principles are *oily*, *resinous*, or *alcoholic*. In the *third* class, the oxygen and hydrogen are in those exact proportions

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18. To what two kinds of analysis may such substances be subjected?
19. What are called the *proximate*, and what the *ultimate principles?*
20. Why is the analysis of plants an operation of great delicacy?
21. Why is not the *sap* accounted a proximate principle?
22. Upon what is the classification of proximate principles founded?

which form water: these are neither acid nor resinous. *Sugar, gum, starch*, with many others, are of this class(23).

Caroline. That is a very satisfactory arrangement, as it gives to us some idea of the composition of a body from its sensible properties. I should like to have a list of these acids and other compound principles, that I might take a glance at the ground over which we are to travel in search of these animal and vegetable remains.

Mrs B. Such a list would be more formidable than you anticipate, and would contain the names of many substances for the examination of which we have neither time nor opportunity. To gratify you, however, I will give you a catalogue of some of these principles, confining it to the vegetable kingdom only. Here it is.

Vegetable Acids.

Acetic,
Oxalic,
Tartaric,
Citric,
Malic,
Benzoic,
Gallic,
Succinic,
Moroxylic,
Hydrocyanic,
Kinic,
Meconic(24).

Substances which are chiefly Alkaline.

Morphia,
Cinchonia,
Quinia,
Strychnia,
Brucia,
Veratria.
Emetin,
Picrotoxia,
Solania,
Delphia(25),

Substances of the Second Class.

Fixed Oils of various kinds,
Volatile oils, a large class,
Camphor,
Resins, numerous,
Gum Resins, of several kinds,
Caoutchouc,
Wax,
Bituminous substances(26).

Substances chiefly of the Third Class, but some of which are not determined.

Sugar,
Fecula, or Starch,
Gum,
Lignin,
Colouring matter,
Tannin,
Gluten,
Gliadine,
Zymome,
Vegetable albumen,
Fungin,
Suberin,
Ulmin, &c.(27).

If this list is too brief, I have the means of adding to it the names of a great many other substances.

Caroline. Indeed, madam, I am more than satisfied with its extent, and have no desire to learn the history of all those bodies which your list presents to us, as I presume that some of them must be quite insignificant personages.

Emily. Do all the acids which you have named exist ready formed in plants, or are not some of them, like carbonic acid, the result of the decomposition of vegetable matter, and the union of its constituents in new forms?

Mrs B. All those which I have enumerated exist in plants either in a free state, or combined with salifiable bases. A few of them also may be artificially produced by the chemist; and in some instances they may be converted into each other, and especially into acetic acid, or vinegar, by processes which abstract a portion of their oxygen(28). With the exception of the oxalic acid, they all consist of oxygen, carbon, and hydrogen, combined in different

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23. How is each of the three classes distinguished?
24. Name such of the *vegetable acids* as you may recollect.
25. Do the same with the *alkaline principles.*
26. What substances compose a part of the second class?
27. What of the third class?
28. What is observed respecting the vegetable acids?

proportions. They are therefore considered as having a double base, carbon and hydrogen, acidified by means of oxygen(29).

We must content ourselves with a short notice of each of these acids. The first on our list, however, we shall defer until a future occasion, for although it is found, in sparing quantities, in some living plants, it is usually a product of fermentation.

Emily. The OXALIC ACID, you have intimated, differs in its composition from the other vegetable acids: this difference, of course, must be in its base?

Mrs B. Whilst all the others contain hydrogen, *oxalic acid* consists, like the carbonic, of oxygen and carbon only; but, unlike carbonic acid, it exists in the solid form, crystallizing in four sided prisms. It is a virulent poison, and many lives have been destroyed by its crystals being mistaken for those of Epsom salts. The sour taste of common sorrel, (rumex acetosa), and of wood sorrel, (oxalis acetosella), is derived from the presence of oxalic acid; not alone, however, but combined with a portion of potassa, in the form of a *binoxalate of potassa*. This, when crystallized, is sold under the name of *essential salt of lemons*, and is used for the purpose of taking iron moulds out of linen. It effects this by forming a soluble salt with the oxide of iron(30).

Emily. The TARTARIC ACID, the second on your list, is, I suppose, the same that we commonly call *cream of tartar*, and which forms so pleasant an acid drink.

Mrs B. *Tartaric acid* exists in vegetables, combined, like the oxalis, with an alkaline base, but not in such a proportion as to form a neutral salt. Common cream of tartar is a *bitartrate of potassa*. It is contained in the juice of the grape; and is found forming an incrustation on the inside of vessels in which wine has fermented(31).

Caroline. This acid you mentioned, I believe, as being contained in Rochelle salt, which you called a *double salt*.

Mrs B. Yes; if the bitartrate of potassa is dissolved, and soda added to the solution until the excess of acid is neutralized, on evaporating the water, beautiful crystals of the *tartrate of potash and soda* (Rochelle salt) will be obtained. *Tartar emetic* is also a double salt, containing potassa and oxide of antimony combined with tartaric acid. Its proper name, therefore, is *tartrate of antimony and potassa*(32).

Caroline. That is a salt for which I have no affinity whatever, and which I am quite willing to place among the incompatibles.

Mrs B. CITRIC ACID is found in many fruits, but principally in lemons and limes. It is frequently preserved in the crystalline form, and used instead of the fresh fruit, in making punch and lemonade. Its salts are called *citrates*(33).

MALIC ACID exists in apples, and in most of the acidulous fruits, accompanied by other acids, and by saccharine matter.

BENZOIC ACID is obtained from a substance called benzoin. Its taste is rather aromatic and pleasant, on which account it is used in some medicinal preparations(34). The *gallic acid* is the only one remaining on our list, to which I shall deem it necessary to require your further attention.

GALLIC ACID is contained in gall nuts, and also in the bark of oak and various trees. It is always combined with other principles, but especially

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29. What are their general constituents, and what exception is there?
30. How is *oxalic acid* found, and what are its properties?
31. Whence is *tartaric acid* obtained, and with what combined?
32. What are *Rochelle salt* and *tartar emetic?*
33. What is said of *citric acid?*
34. In what are *malic* and *benzoic acids* contained?

with *tannin*. When these substances are infused in water, the *gallic acid* is dissolved(35). In this phial I have a solution of gall nuts, which, although of a brownish colour, is perfectly transparent; and in this other phial I have a solution of sulphate of iron. Observe the effect when I mix together a small portion of each of them.

Emily. They have instantaneously become as black as ink, and are quite opake!

Mrs B. They have actually formed ink. The most distinguishing property of gallic acid is, that when combined with the salts of iron, it produces an intensely blue colour, approaching to black(36). This acid can be obtained in the crystalline state: its taste is both sour and astringent. With the exception of that formed by its combination with iron, its salts are unimportant.

Emily. Are not the gall nuts somewhat similar to the oak apples which we frequently see in this country?

Mrs B. They are both produced in the same way; that is by the puncture which an insect makes for the purpose of depositing its egg. The oak apples, however, are soft and spongy, whilst gall nuts are solid and hard. The best kind come from the countries on the Levant, and are called Aleppo galls. They are extensively used, not only in the making of ink, but also for the purpose of dyeing a black colour(37).

We shall now notice, in a brief way, a very important class of compounds which the chemist has extracted from various vegetable substances, and in so doing has furnished the physician with the active principles of many plants, divested of the inert, and, in some instances, the injurious substances with which they are mixed, or combined, in the plant: I allude to the VEGETABLE ALKALIES.

Caroline. These are very different substances from potash, which you informed us was at one time called the vegetable alkali, as they are actually vegetable principles. They must consist of the very same ingredients as the acids which we have just been considering(38).

Mrs B. It appears that the vegetable alkalies contain nitrogen, in addition to the three principles found in all vegetables. Two or three examples of these alkalies will suffice to give you an idea of their nature and use.

MORPHIA is found to be the narcotic principle of opium; but in that drug, there are various other substances, one of which is called *narcotine;* and it is from the presence of this article that proceed the extremely unpleasant effects produced upon some persons by the use of opium. When the *morphia* is procured in a separate state, the soothing effects of opium are produced without that feverish excitement which so often results from laudanum and opium, as usually administered(39).

CINCHONIA, and QUINIA, or QUININE, are alkaline principles, and both contained in Peruvian bark. They are also bitter principles, and although evidently different from each other, are analogous in their medicinal properties. They both form salts with nearly all the acids. That which is most employed is the *sulphate of quinia*. In this substance the active principle of the bark is so concentrated, that two or three grains of it have proved as effectual in curing intermittent fever, as many ounces of the solid bark(40).

We will now pass on to the second class of the vegetable proximate principles.

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35. Whence is *gallic acid* procured, and with what is it combined?
36. What is produced by its mixture with sulphate of iron?
37. How are gall nuts produced, and in what countries?
38. What is said respecting the *vegetable alkaline principles?*
39. What observations are made respecting *morphia* and *narcotine?*
40. What in relation to *cinchonia* and *quinia?*

Emily. That is to the oily, resinous, and alcoholic substances, in which the hydrogen, when compared with the oxygen, is in excess.

Mrs B. Oils are divided into *fixed*, and *volatile*. FIXED OILS are so called because they require a very high degree of heat to convert them into vapour; whilst the *volatile oils* evaporate at the common temperature of the atmosphere. A drop of fixed oil will produce a permanent spot of grease upon paper; whilst a drop of volatile oil will rapidly evaporate, especially if the paper be held before the fire(41).

Caroline. Nuts sometimes contain a large quantity of oil; and I believe that it is from the seeds of plants that the oils are always obtained.

Mrs B. Olive oil is extracted from the pulp which surrounds the stone; but the *fixed oils* are usually contained in the seeds only. They are generally obtained by bruising the seeds, and then putting them under a press in strong bags made of hemp or horse hair. Linseed oil is thus pressed from the seed of flax. Walnuts, almonds, and poppy, cotton, sun-flower, rape, and many other seeds, supply considerable portions of oil(42).

Emily. There is one very striking difference between these fixed oils; the linseed and nut oils which I use in my painting, dry and become hard, which would never be the case with olive oil.

Mrs B. These are called *drying oils*, and they appear to possess this property in consequence of their affinity for oxygen, of which they absorb a large quantity, and thus become converted into hard substances, resembling the resins(43).

Caroline. If they absorb a large quantity of oxygen, I wonder they do not heat, and take fire, as this would seem to be a natural result.

Mrs B. Recollect that to produce combustion the absorption must be rapid as well as great. It is a fact, however, that combustion has frequently taken place from this cause. If hemp, cotton, or similar materials be moistened with drying oil, and laid in a heap, it will, in the course of a few hours, heat and take fire. Many destructive conflagrations have resulted from *spontaneous combustions* of this kind. When a single article is oiled, and exposed to the cooling influence of the atmosphere, the heat will be carried off as fast as it is generated; but where there is a mass of the material, the heat is retained and accumulated(44).

Emily. From your remark that the *fixed oils* are usually contained in the seeds only, and are procured by pressure, I infer that such is not the fact as regards the *volatile oils*.

Mrs B. The VOLATILE, or ESSENTIAL OILS, form the basis of all the vegetable perfumes. Essential oil is contained, more or less, in every part of an odoriferous plant, excepting the seeds. Many flowers contain it in considerable quantities.

Emily. It is then from essential oil, I suppose, that their odour proceeds?

Mrs B. Yes; and this oil is frequently obtained from flowers. In a few instances, as from the rind of lemons and oranges, essential oil may be obtained by simple pressure: this, however, can very seldom be done(45).

Caroline. Is it not very plentiful in the leaves of mint, and of thyme, and all the sweet smelling herbs?

Mrs B. Yes, remarkably so; and in geranium leaves also, which have a much more powerful odour than the flowers.

The perfume of sandal fans is an instance of its existence in wood. In

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41. How are *fixed* and *volatile oils* distinguished?
42. In what way and from what parts are the fixed oils procured?
43. By what are the drying oils distinguished?
44. How do they occasionally produce spontaneous combustion?
45. In what parts of a plant are the essential oils found?

short, all vegetable odours, or perfumes, are produced by the evaporation of particles of these volatile oils(46). The usual mode of obtaining essential oils is by distillation. The aromatic plant is put into a still, along with water, without which the vegetable would be burnt. The essential oil and water pass over, and are condensed in a receiver. The oil, being insoluble in the water, floats upon its surface, or sinks to the bottom, according to its specific gravity(47).

Emily. What is the difference between what are called *essences* and the volatile oils.

Mrs B. The volatile oils are soluble in alcohol, and the essences are solutions of this kind: thus essence of peppermint consists of the essential oil of peppermint and alcohol. Essences are formed by using ardent spirit, or alcohol, instead of water, in the distillation of the aromatic plants(48).

The essential oils evaporate but slowly at common temperatures; and, like the drying oils, when exposed to the atmosphere, they absorb oxygen, thicken, and at length acquire a consistence resembling the resins(49).

The cheapest and most useful of the essential oils, is the *oil*, or *spirits, of turpentine*, which is procured by distilling the turpentine which oozes from the pine tree. Common rosin is the substance which remains in the still, after the volatile oil is driven over(50).

Caroline. Pray does not the powerful smell of *camphor* proceed from a volatile oil?

Mrs B. CAMPHOR, although closely allied to the volatile oils in many respects, seems in others to stand alone. It is obtained from a tree in Japan, called the *laurus camphora.* Like the essential oils it is diffused throughout the plant, and is separated from the trunk, root, and branches, by *sublimation.* Camphor is found in small quantities in various other plants.

Camphor is soluble in the essential and fixed oils, and in alcohol, but is insoluble in water. By its aid *copal,* one of the resins, may be rendered soluble in alcohol, and converted into a varnish(51).

Emily. The different varnishes are, I know, made from the resins, and as I sometimes use them, I feel interested in learning something further respecting their composition.

Mrs B. The RESINS are the inspissated juices of plants, which, although they resemble the *gums* in appearance, differ from them essentially in their properties. The different kinds of gum are soluble in water, whilst in this fluid the resins are completely insoluble, their proper solvents being the fixed and volatile oils, alcohol and ether. The resins are also dissolved by means of the fixed alkalies. They undergo fusion by heat, are extremely combustible, affording a brilliant light, and, like the oils, produce in their combustion carbonic acid and water(52).

The principal resins are *common rosin, copal, lac, sandarach, mastich,* and *elemi.* All these when dissolved are used in varnishes(53).

Emily. But I believe they are not all soluble in the same fluids, as the spirit and oil varnishes usually contain different resins.

Mrs B. They are, in some instances, and under proper management, soluble in the essential and fixed oils, and also in alcohol; but, in general,

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46. What particular plants are named as abounding in it?
47. How are the essential oils usually procured?
48. In what do the *essences* differ from the essential oils?
49. What change does the atmosphere produce in them?
50. What is *spirits of turpentine,* and what *rosin?*
51. What is *camphor,* and what is said respecting it?
52. What are the *resins,* and what are their properties?
53. Name some of the principal resins.

they have their appropriate solvents, and become the basis of oil or of spirit varnishes, according to the difference in their natures(54).

Caroline. Is not *amber* a resin? it has that appearance, and I have heard of amber varnish.

Mrs B. AMBER is a peculiar resinous substance, undoubtedly of vegetable origin; but it is sometimes dug out of the earth, and at others collected in certain places on the sea shore. Its precise origin is unknown, but it is certainly a vegetable product, as it frequently includes insects, and small pieces of plants within its substance(55).

There is a mixture of essential oil, of resin, gum, and other matter, obtained in a concrete state, from different plants, and called GUM-RESINS. *Aloes*, *gamboge*, and several other useful compounds belong to this class(56).

Emily. Does not *gum elastic* also belong to the same family? it is a very inflammable substance, as I have frequently observed.

Mrs B. CAOUTCHOUC, or *gum elastic*, when first procured from the plants which contain it, is a white, milky, glutinous fluid; it acquires consistence and blackens in drying.

Caroline. I am surprised to hear that gum elastic was ever white or ever fluid. From what vegetable is it procured?

Mrs B. There are two or three different species of trees in the East Indies and South America, from which it is obtained by making i[illegible]sions in their stems. The juice is collected as it trickles from these incisions, and moulds of clay, in the form intended to be given to the bottles of gum elastic, are dipped into it. A layer of this juice adheres to the clay, and dries on it; and by repeating this operation, several layers are successively added until the bottle is of sufficient thickness. It is then beaten to break down the clay, which is easily shaken out. Shoes and boots are also made of it by a similar process. They are extremely pleasant and serviceable, both from their elasticity, and their being perfectly water proof(57).

We will next say a few words respecting the *wax* which is collected by that industrious insect the bee.

Emily. I recollect that Huber, in his most interesting work upon bees, considers wax as an animal, rather than a vegetable, product; as he found that bees made combs of wax even when they were fed exclusively upon sugar.

Mrs B. WAX partakes of the nature of a concrete fixed oil, and appears to be both of vegetable and of animal origin. The fact you mention seems clearly to prove the latter, whilst the former is evident from its being contained in the pollen of flowers, and from its forming a coating to the plum, and to the leaves of many plants; and more especially from the quantity obtained under the name of *myrtle wax*, from the berries of the *myrica cerifera*. There appears, however, to be some difference in the composition of that procured directly from plants and that furnished by the bee.

Wax is frequently made into candles, as it affords a purer light than most other substances. Before being used for this, and several other purposes, it is in general bleached, and rendered perfectly white(58).

Caroline. In your list of vegetable principles of the second class, you have inserted *bituminous substances.* I had always supposed that these were dug out of the earth, and properly belonged to the mineral kingdom.

Mrs B. They may, perhaps with equal propriety, be classed as belonging either to the mineral or the vegetable kingdom; for although the bitumens

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54. What is said respecting their solution, and of *varnishes?*
55. What are the origin, sources, and properties of *amber?*
56. What is the nature of the *gum-resins?*
57. Give the history of *caoutchouc*, or *gum elastic.*
58. Do the same in relation to *wax.*

are found in the earth, they are undoubtedly of vegetable origin. They may be conveniently arranged under the heads of *Bitumen* and *Pit coal*(59).

The name BITUMEN includes *naphtha*, which has been already noticed, (p. 164) *petroleum*, and *mineral tar*. They are very viscid fluids, bearing a strong resemblance to each other. They are found in many coal districts, and, by exposure to the air, become solid, and appear much like common pitch. The bitumens are distinguished by their inflammability(60).

Emily. Common pitch and tar, however, are not mineral substances; as they are brought from the pine districts, where turpentine is prepared.

Mrs B. Turpentine exudes from the growing pine tree; but *tar* is extracted from the wood by means of heat, and consists of the turpentine partially decomposed, and mixed with other vegetable products. When the more fluid parts are evaporated by boiling, the tar is converted into *pitch.* The difference between them and mineral tar, and mineral pitch, is not greater than might be expected in substances having the same origin, but obtained by different processes(61). *Asphaltum*, sometimes called *Jew's pitch*, is a much purer bitumen than common pitch. It is found on the banks of the Dead Sea, and in the islands of Barbadoes and Trinidad, forming large beds in the earth. Dissolved in spirits of turpentine, it forms a dark coloured varnish much used for some purposes(62). Articles very similar to most of these bitumens may be extracted from *pit coal.*

Caroline. It is no easy thing to believe that the vast beds of pit coal existing in various parts of the world, and buried far below the surface of the ground, have all originated from vegetable materials. Wood and coal bear but little resemblance to each other, excepting in the fact that they are both combustible.

Mrs B. In a comparison of this kind the fact of a similarity in composition is a point of much greater weight than that of mere combustibility. But we have still stronger evidence, in the fact that specimens are sometimes found in coal mines, one part of which exhibits the organic structure of the wood, in the form of charcoal, whilst another part is completely converted into pit coal. The slate which usually covers the beds of pit coal, abounds also in petrified vegetable remains. This however is a point which it is not our present business to discuss(63).

Emily. In pit coal itself there must be a great difference of composition. The *anthracite* of Pennsylvania, and the coal brought from Virginia or from England, burn as differently as do charcoal and yellow pine wood.

Mrs B. The difference between the two is precisely that which exists between the articles that you have named. One of them contains a bituminous, or resinous substance; the other does not(64). The best *anthracite* is nearly pure carbon; and if we take the *bituminous coal*, and treat it as we do pine wood when we convert it into charcoal, the bitumen will be volatilized by the heat, mineral tar and pitch may be collected during the process, and a species of charcoal will then remain, which is called COKE. Excepting in its being very porous, this substance is very similar to anthracite, and it is pre-

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59. What observations are made respecting the *bitumens?*
60. What are the names of the *fluid bitumens?*
61. What is said respecting *turpentine*, *tar*, and *pitch?*
62. Where is *asphaltum* found, and what is it used for?
63. What circumstances prove the vegetable origin of *pit coal?*
64. In what consists the difference between *anthracite* and the common pit coal?

pared and used in great quantities in the English iron manufactories as substitute for charcoal(65).

What I have further to say upon vegetable chemistry will afford us full occupation during our next meeting.

CONVERSATION XXIX.

ON VEGETABLE CHEMISTRY—CONTINUED.

Vegetable Principles of the Third Class. Sugar and its Manufacture. Molasses, Loaf-sugar, Sugar-candy, and Barley Sugar. Honey, Sugar of Grapes, and Manna. Gum or Mucilage. Distinction between Gums and Resins. Fecula or Starch, Arrow Root, Tapioca, and Sago. Fecula converted into Sugar by Sulphuric Acid, by Fermentation, and by Germination. Malting. Gluten. Tannin. Lignin or Woody Fibre. Colouring Matter, Lakes, and Dyeing. Adjective and Substantive Colours, and Mordants. Fermentation. Saccharine. Vinous. Use of Yeast. Nature and Combustion of Alcohol. Ethers. Sulphuric Ether. Aphlogistic Lamp. Acetous Fermentation, Acetic Acid, Vinegar, and Pyroligneous Acid. Products of the Putrefactive Fermentation.

Mrs B. Our first business to-day will be to examine a few of those vegetable principles which constitute the third class; that in which the oxygen and hydrogen are to each other in the proportion, by weight, of eight to one, or, in other words, in the exact proportions for forming water(1). The first of this class of substances which will claim your attention is *sugar*.

Caroline. Should all the members of the class possess qualities equally agreeable, we shall find ourselves in very pleasant company.

Emily. SUGAR, I know, is contained in a great number of vegetables; I have seen some beautifully white, which was made in France from the juice of beets; and our own maple sugar, too, I have frequently eaten, and think its flavour peculiarly agreeable.

Mrs B. There are few vegetables which do not contain sugar(2), but it is so much more abundant in the sugar cane *(arundo saccharifera)* than in any other plant, that, excepting under particular circumstances, the whol supply, both for Europe and this country, is obtained from it.

Caroline. I have read the description of the mode of making sugar i the West Indies and in Louisiana, and know that the juice of the cane i pressed out, by passing it between large iron rollers; after which, the water part is evaporated by boiling, and the solid part collected in the form o brown, or moist sugar(3).

Mrs B. The juice, when pressed out of the cane, contains a portion o vegetable acid, and of mucilaginous matter, which requires to be removed this is, in great part, effected, during the boiling, by the addition of lime water, the lime neutralizing the acid, and causing much of the foreign matte to rise to the surface, whence it is taken by skimming. The juice, whe sufficiently concentrated, is drawn off into wooden coolers, in which th sugar crystallizes. It is then, however, of a very dark colour, owing to th

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65. What is *coke*, and for what purpose is it used?

1. What characterizes the vegetable principles constituting the thi class?

2. Is *sugar* a common product of vegetables?

3. In what plant is it most abundant, and how is it procured?

presence of that brown, siropy fluid, *molasses*. To get rid of this it is put into barrels, the bottoms of which are perforated with numerous small holes, through which the molasses gradually drains off. The common brown sugar is thus prepared for market(4).

Emily. But a considerable portion of sugar must still be contained in the molasses, as its taste fully indicates.

Mrs B. Yes, but it is so intimately mixed with other vegetable matters, as to prevent its crystallization. This fluid, however, is not lost, as much of it is used with articles of food, and large quantities are employed in the distillation of rum(5).

Loaf-sugar, is prepared by redissolving the brown sugar, and refining it in such a way as to remove the whole of the molasses, and other foreign matter: it is then, as you know, a solid white substance, of a crystalline texture, and of a pleasant, simply sweet taste. By its ultimate analysis, an atom of sugar appears to consist of one atom of carbon, one of oxygen, and one of hydrogen.

Caroline. And in what way is it converted into sugar-candy, and barley sugar, which seem to consist principally of this material?

Mrs B. Sugar-candy is made by dissolving sugar in water, and allowing the water to evaporate very slowly; the sugar is then deposited in large compact crystals. Barley sugar is prepared by melting sugar over the fire, pouring it out in its fused state, and cutting it into sticks. It is usually flavoured by means of some of the essential oils(6).

Honey, which the industrious bee collects from various flowers; *manna*, which is a concrete juice obtained from several species of ash; the *sugar of grapes*, and some other saccharine materials, although they contain principles very analogous to sugar, do not appear to derive their sweet taste from the same identical ingredient. The sweet matter of manna has been procured in a separate state, and has received the name of *mannite*. Most of these vegetable juices, as they ooze or are expressed from the plant, contain considerable portions of the principle called *gum*, or *mucilage*(7).

Emily. That is a substance with which we are well acquainted, particularly with the kind called gum arabic. Gum is also very common on the bark of the plum and peach tree.

Mrs B. GUM, which, when in solution, is called *mucilage*, is contained in most plants, but the most useful is that which is obtained from a species of the Acacia tree growing in Arabia, whence it derives its name of *gum arabic*. It is procured in such quantities as to be exported to most parts of the world. It contains much nutriment, and forms a considerable part of the food of the natives of those countries which produce it.

Although there are several species of gum, it is probable that they all contain the same principle, and that they derive their peculiar properties from the different vegetable products with which this principle is combined in the respective plants by which it is furnished(8).

Emily. In its external appearance, gum resembles the resins, but it differs from them in being soluble in water, whilst they are insoluble.

Mrs B. A resin will be precipitated from its solution in alcohol, if water be added to it, and a solution of gum in water, will, in like manner, be decomposed by the addition of alcohol. The cause of the precipitation is the

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4. Relate some of the particulars of the manufacture.
5. What is observed respecting the sweet taste and the uses of *molasses?*
6. How are *loaf-sugar*, *sugar-candy*, and *barley-sugar* prepared?
7. What is observed respecting *honey*, the *sugar of grapes*, and *manna?*
8. Whence is *gum* or *mucilage* obtained, and what is said of it?

same in both cases; namely, the affinity of water and of alcohol for each other being such as to deprive the gum, or the resin, of its solvent.

Caroline. I now know why some spirit varnish was spoiled by my pouring a little water into it. The resin separated, and fell to the bottom, in consequence of the water depriving it of the alcohol which had held it in solution(9).

Mrs B. STARCH, or FECULA, is very abundant in the vegetable kingdom. That which is generally used is obtained from wheat; but the common, and the sweet potato, yield it in large quantities. The Indian *arrow root* is only a very pure starch. *Tapioca* and *sago*, also, are chemically the same with fecula, but somewhat modified and altered by the heat employed in their preparation. Starch is insoluble in cold water, although hot water will dissolve it completely(10).

Emily. Starch, as we buy it, appears to be somewhat crystalline in its form; but yet its texture does not at all resemble that of crystals.

Mrs B. This appearance is a consequence of its contraction in the process of drying in the manufactories. You have often in dry weather observed hard, clayey paths cracked or divided in a similar way(11).

In its composition, starch is very nearly allied to sugar, and may be wholly converted into saccharine matter by boiling it in water containing a small portion of sulphuric acid. Frost produces a similar effect upon the fecula contained in the potato, and in other vegetables, several of which, you know, acquire a peculiar sweetness by being frozen(12).

When seeds begin to germinate, their starch is converted into sugar, which, being soluble, becomes the food of the embryo plant. In the process of malting barley, the grain is first moistened, and allowed to sprout; and then heated sufficiently to arrest its further growth. It is thus rendered saccharine, and fitted for the use of the brewer or distiller(13).

Caroline. Although starch is obtained from wheat, the difference between it and flour is very great. I think that starch would answer but indifferently in the hands of the baker or of the cook, for making loaves or puddings.

Mrs B. The different kinds of grain contain a principle called GLUTEN. This principle is more abundant in wheat than in either of the other farinaceous plants. The soluble materials, and the fecula, may be washed out of flour; and when this is done, the gluten will be obtained in a separate state. This substance is very tenacious and elastic, of a gray colour, and fibrous texture. Like animal matter, it contains nitrogen, and if left in a moist state will soon putrefy. The tenacity of paste made from wheat flour, and also the nutritious quality of wheat bread, result principally from the gluten in their composition(14). Two proximate principles have been discovered in gluten, one of which has been named *gliadine*, the other *zymome.*

Caroline. What a complex affair is a common loaf of bread! To make it we have to take the fecula, gluten with its gliadine and zymome, some water, and yeast, a portion of muriate of soda, with a little pearl ash, besides all the contaminations of all these ingredients; we mix them together, and call the compound simple bread. The very list of materials would supply a column for a dictionary(15).

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9. By what properties are the gums and resins distinguished?
10. Whence is *fecula* or *starch* obtained, and what are its properties?
11. What causes its columnar, or crystal-like appearance?
12. By what means may *fecula* be converted into sugar?
13. What are the effects of germination, and what is *malting?*
14. Detail the properties of *gluten*, and the mode of obtaining it.
15. What observation is made respecting the composition of bread?

Mrs B. We shall soon dismiss these proximate principles, and proceed to the spontaneous decomposition of vegetables. But, before doing this, *tannin*, *lignin*, and the *colouring* matters of plants, will claim some notice.

TANNIN exists in large quantities in all astringent plants, and may, indeed, be considered as their astringent principle. It is sometimes found alone, but is more frequently accompanied by *gallic* acid, as in gall nuts, the bark of oak and other trees, in the unripe persimmon, and in tea. Like gallic acid, it precipitates the salts of iron of a black colour; and combined with the gallate of iron forms the basis of writing ink, and of the usual black dyes. Its most important use, however, is in the process of *tanning*, or the conversion of the skins of animals into leather; a circumstance which I shall particularly explain when we treat of animal chemistry(16).

Mr Hatchett, a chemist of much celebrity, obtained a substance bearing a strong resemblance to tannin, by digesting charcoal and nitric acid together. Their product has been named *artificial tannin.*

Emily. And has not this discovery been of great use to the manufacturers?

Mrs B. Nature furnishes tannin in so many of her productions, and at so little cost, that were the artificial exactly like the natural tannin, still its price would be too great to make the discovery useful in an economical point of view; although, as a scientific fact, it may be of real importance(17).

LIGNIN, or the WOODY FIBRE, constitutes the great body of a plant, giving to it its solidity and support, as the animal frame is sustained by the bones.

Emily. It must be from the *lignin*, then, that common charcoal is formed.

Mrs B. The *woody fibre*, as a proximate principle, consists not only of carbon, but of the ordinary constituents of vegetable matter. To obtain lignin in a separate state, wood, in form of shavings or of saw dust, is alternately digested in water, in alcohol, and in dilute muriatic acid: all the soluble parts will be thus removed, and the lignin alone remain. It has neither taste nor smell, and undergoes no change by keeping. Dry wood is said to contain about ninety-six per cent of lignin(18).

By digesting lignin for some time with sulphuric acid, it is changed into a substance resembling gum, and this by boiling, may, like fecula, be converted into sugar.

Caroline. One of the last articles which I should have thought of transforming into sugar, would have been saw dust. The similarity which exists between the different vegetable compounds, might, however, when duly weighed, induce us to suspect that agents which have the power to change the proportions, or alter the arrangement of the atoms of their elements, might sometimes convert one of these vegetable principles into another(19).

Mrs B. The COLOURING MATTER found in plants has sometimes been classed as a distinct principle; but colouring materials differ so much from each other in their solubility, and in their other properties, as to render the propriety of such a classification very doubtful. The colouring matter is always attached to some one or more of the proximate principles, such as the mucilaginous, farinaceous, and resinous. These, if there is a separate colouring principle, so far modify its properties as to render it necessary to treat it by very different processes, when it is applied in the arts of painting or dyeing(20).

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16. What are the sources, properties, and uses of *tannin?*
17. What is said respecting the discovery of *artificial tannin?*
18. What is *lignin*, and how is it obtained in a separate state?
19. What is said on the conversion of lignin into sugar?
20. What observations are made on the colouring principle?

Emily. The LAKES, I believe, are all of them vegetable colours, and most of them, I know, are fugitive when used in painting.

Mrs B. The lakes consist of vegetable colouring matter, combined with alumine, or with some other metallic oxide, to which they have an affinity, and with which they form insoluble compounds(21). Some of the vegetable colours that are used in dyeing will at once attach themselves to the fibres of the material to be dyed, and such are called *substantive colours;* but many of them will impart a mere stain, which is readily washed out, and these are denominated *adjective colours.* To cause the latter to attach themselves permanently, the cloth to be dyed is first dipped into a solution of some substance which has an affinity to its fibres, and also to the colouring matter which is to be employed. When this has been effected, the cloth may take a permanent dye in a liquid that would otherwise scarcely have discoloured it(22).

Caroline. Dyeing, then, must be a chemical art, as it does not, like painting, consist in merely covering a substance, mechanically, with colouring matter.

Mrs B. Undoubtedly. The condition required to form a good dye, is that the colouring matter should be precipitated, or fixed, on the substance to be dyed, and should form a compound not soluble in the liquids, or removable by the other agents to which it will probably be exposed. Thus, for instance, printed or dyed linens or cottons must be able to resist the action of soap and water, to which they must necessarily be subjected in washing; and woollens and silks should withstand the action of grease and acids, to which they may be accidentally exposed(23).

Caroline. Then if linen and cotton have not a sufficient affinity for the colouring matter, the combination is effected by the intervention of a third substance?

Mrs B. Yes; and this third substance is called a *mordant*, or *basis.* Many articles to be dyed are dipped into a solution of alum, the alumine of which has an affinity for the substance of the cloth, and attaches itself firmly to it. When dipped into the dyeing liquid, the affinity of the alumine for colouring matter is then brought into operation, and the colour permanently precipitated upon the cloth. The alumine is, in this case, the mordant, or basis(24).

Emily. This is an exemplification of the fact that two substances which have no apparent affinity for each other, may be made to combine by the intervention of a third; just as oil and water, which will not unite when alone, combine and form soap if an alkali is added to them(25).

Mrs B. The preceding examples of the compounds secreted by the organs of plants, will suffice to give you a clear idea of their general properties; and we will now proceed to investigate some of the effects produced by the SPONTANEOUS CHANGES OF VEGETABLE MATTER. You are already aware that the simples and compounds contained in vegetable substances, enter into new forms of existence, when they are no longer controlled by the living principle. The examination of these changes will present a wide field for investigation, of which we shall be able to explore only a small part.

Caroline. The term *fermentation*, I know, is applied to such changes; but it appears to me that it is rather indefinite, as the effects which it produces are so various. Thus manure, bread, beer, vinegar, and many other articles, are said to ferment when they are undergoing certain changes; but

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21. How are the vegetable colours called *lakes* obtained?
22. What are *adjective* and what *substantive colours*, as used in dyeing?
23. What is required in dyeing, and why is it a chemical art?
24. What is a *mordant* or *basis*, and what does it effect?
25. What law of chemical affinity does it serve to exemplify?

some of them spoil by fermentation, whilst others acquire properties which are highly valued by us(26).

Mrs B. In many cases of fermentation, there is a visible intestine motion in the materials undergoing the process: this motion is occasioned by the extrication of gaseous matter. Sometimes, however, there is no gaseous matter evolved, or if there is, the change takes place so slowly that it is imperceptible. As the vegetable principles vary so much in their natures, their operation upon each other, or that of other agents upon them, must necessarily be different; and this has given rise to the division of the fermentative process into four kinds, namely, the *saccharine*, the *vinous*, the *acetous*, and the *putrefactive* fermentation(27).

Emily. These terms are very expressive, as they evidently point to the production of sugar, of wines and acids, and of the final change to which all vegetable and animal materials appear to be liable.

Mrs B. The SACCHARINE FERMENTATION appears principally to take place in *fecula*, or *starch*. The circumstances under which it occurs have been so recently noticed, that I need not repeat them(28). I shall therefore pass at once to the second kind, which is the VINOUS FERMENTATION. Although this name is derived from the fermentation which gives rise to the production of wine, it is the same process which takes place in cider, beer, and other liquids when they acquire an intoxicating property by being allowed to ferment, and they are all included under the general name of vinous liquors(29).

Caroline. I have often thought it a curious circumstance that we may drink a large quantity of sweet cider, without any danger of being made giddy by it; whilst a tumbler of fermented cider might prove a little too much for our gravity.

Mrs B. It is absolutely necessary to the production of the vinous fermentation that saccharine matter should be present in the liquid which is to undergo that process. The juices of fruits usually contain all the sugar that is necessary; and in beer and ale it is supplied by the malting of the grain, which has converted its starch into sugar. When a fluid containing the necessary ingredients is exposed to a temperature of from sixty to seventy degrees of heat, the operation soon commences. Bubbles of gas escape from it, and presently the whole volume of the liquid is in brisk motion; its appearance is turbid, its surface covered with froth, and its temperature will be found to have risen several degrees above that of the surrounding air. After the lapse of a few days, the gas ceases to escape, the temperature falls, the impurities subside, and the liquor becomes clear and transparent. The process is then considered as completed, and the properties of the liquid are completely altered(30).

Emily. And what are the precise changes which occur during this fermentation?

Mrs B. A large part of the sugar has disappeared, and, in its stead, *alcohol* has been formed, which being mixed in the fluid communicates to it its stimulating and intoxicating properties(31).

Caroline. And is sugar all that is necessary to this fermentation? If so, sugar and water may be converted into spirit.

Mrs B. Although it is the sugar only that is decomposed, something else is necessary to cause the fermentation to begin. The mucilage, and other

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26. What remarks are made on the use of the term *fermentation?*
27. What takes place in fermentation, and what kinds are named?
28. In what principle does the *saccharine fermentation* occur?
29. What is said of the *vinous fermentation* and *vinous liquors?*
30. What are the circumstances attendant on the vinous fermentation?
31. What are the precise changes effected by it?

principles existing in the juices of fruits, suffice for this purpose; but if sugar alone be contained in the water, it is necessary to add some *yeast*, which is itself a peculiar product of fermentation, and is specially adapted to promote it. By this addition, sugar and water may be actually converted into spirit and water(32).

Caroline. I have often heard of the distillatiôn of spirits from potatoes, and from other roots, as well as from grain, and the juices of fruits: in this case it would seem that spirit may be formed without the presence of sugar.

Mrs B. But all these substances contain a considerable quantity of starch, which first undergoes the saccharine fermentation, and thus furnishes the sugar necessary to the vinous(33).

The manner in which the ardent spirit, or alcohol, is separated from the fermented liquor, I described to you in one of our early conversations, (p. 62), and showed you an alembic, or still. I need not, I am sure, repeat what I then said(34).

Emily. You have not informed us, Mrs B., in what the decomposition of the sugar consists, or what is the kind of gas disengaged in this fermentation. I know enough, however, about breweries and distilleries to be at no loss on the latter point; besides which, I now recollect that you told us, some time since, that the gas in question was carbonic acid.

Mrs B. An atom of alcohol consists of one atom of oxygen, united to two of carbon and three of hydrogen. When by fermentation a portion of the sugar is converted into carbonic acid, the remaining ingredients are in the precise proportions for forming alcohol, which is, consequently, the result of this decomposition(35).

Caroline. Pray what is meant by *proof spirit?* I know that it relates to its strength, but do not fully understand the meaning of the term.

Mrs B. When a vinous liquid has been so far *rectified* by distillation as to contain about equal parts of alcohol and water, it is then called proof spirit. When of greater strength, it is named second, third, or fourth proof, according to its state of concentration; and when as much as possible of the water has been separated from it, it is then *spirits of wine*, or rather *alcohol*(36).

Alcohol, you know, is extremely inflammable. When burnt, it is, from the nature of its constituents, wholly converted into water and carbonic acid, and it is a fact which a person ignorant of chemistry would scarcely credit, that either of the products of its combustion will considerably outweigh the alcohol which has been burnt.

Emily. Because both its carbon and its hydrogen obtain oxygen from the atmosphere, with which they combine, and thus acquire the additional weight(37).

Mrs B. Although ETHER is not produced by the spontaneous decomposition of vegetable matter, but is artificially obtained by the dęcomposition of alcohol, I shall now give you some account of its formation. The experiments which we have performed with it have rendered you familiar with its volatility, and also with the facility with which it takes fire and burns. There are several species of ether, produced by the action of different acids upon alcohol: the most common, however, is *sulphuric ether*, and to this we shall confine our remarks(38). Do you recollect how we obtained the *olefiant* or *heavy carburetted hydrogen* gas?

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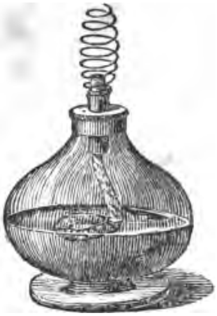
32. What is necessary to the commencement of this fermentation?
33. What is observed on distilling spirits from potatoes, &c.?
34. Explain the nature of distillation, as described at page 62.
35. What are the atomic changes when alcohol is produced?
36. What is meant by *proof spirits* and by *alcohol?*
37. What is observed respecting the combustion of alcohol?
38. How are the different kinds of *ether* produced from alcohol?

Caroline. Oh yes. The experiment was too striking to be so soon forgotten. To procure the gas you decomposed alcohol by the agency of sulphuric acid.

Mrs B. And by a similar process *ether* is obtained, only the decomposition is not carried so far in the latter case as in the former. Whilst an atom of alcohol consists of one atom of oxygen, two of carbon, and three of hydrogen, *ether* is composed of one atom of oxygen, four of carbon, and five of hydrogen. It differs from alcohol therefore in containing a less quantity both of oxygen and hydrogen in proportion to the carbon. To convert alcohol into ether, it is boiled in a retort with sulphuric acid; the affinity of this fluid for water enables it to abstract one half of that which enters into the composition of the alcohol, when the remaining atoms are in such proportions as by their combination to form ether(39).

I will now exhibit to you a very curious instance of the combustion of the vapour of alcohol or ether.

The Aphlogistic or Flameless Lamp.



Emily. The little lamp which you have placed upon the table has its wick surrounded by a coil of wire, which appears like silver.

Mrs B. The wire is platinum, and the lamp is called the *aphlogistic* or *flameless lamp.* It depends for its operation upon an interesting fact discovered by Sir Humphry Davy, that if a coil of platina wire is heated, and then held near the surface of ether or of alcohol, in a glass, it will become of a glowing red heat, and will continue so until the whole of the ether or the alcohol has evaporated. I have some ether in this lamp; I will light the wick, and then blow it out, and you will perceive the effect produced upon the platina wire.

Caroline. It is extremely curious; the wire does indeed continue red hot, and that without any apparent cause, as there is no flame.

Mrs B. The vapour of the ether burns as it escapes, but not with sufficient heat to cause it to inflame, although with enough to keep the wire red hot, which in its turn continues this flameless combustion of the ether(40).

We will now converse awhile about the formation of *acetic acid,* the principle which communicates a sour taste to vinegar.

Emily. We very well know the effect of this fermentation upon our beer and cider, although we have much to learn respecting its chemical nature. It seems however that this fermentation succeeds to the vinous.

Mrs B. The ACETOUS FERMENTATION does, as you observe, succeed to the vinous; and in some instances so quickly that it is difficult to complete the one before the commencement of the other. The acetous fermentation consists in the decomposition of the alcohol formed in the vinous, and its conversion into *acetic acid*(41).

Caroline. But alcohol contains so little oxygen, that it is difficult to conceive how it can become an acid, unless it should be one of the hydracids.

Mrs B. The acetous fermentation requires the exposure of the liquid to the action of the atmosphere, from which it absorbs a large portion of oxygen. The appearances which accompany this fermentation are in several respects similar to those which accrue in the vinous, and it is effected at the same degree of temperature. Although the internal motion is less violent, it still exists, and is accompanied by an escape of carbonic acid; the

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39. Give the process for the formation of *sulphuric ether.*
40. Describe the structure and operation of the *aphlogistic lamp.*
41. What fermentation follows the vinous, and what does it produce?

temperature of the liquor rises, and it becomes at first turbid, and afterwards clear. When the process is completed not an atom of alcohol remains, the whole being converted into acetic acid(42).

Emily. Pray what is the precise difference between vinegar and *acetic acid?*

Mrs B. Vinegar is sometimes made from wine, sometimes from cider, beer, infusions of sugar or molasses in water, or other similar mixtures, to which yeast or some other ferment is added. When the acid is formed, it is necessarily mixed with whatever vegetable matter the liquid contained, and receives different flavours according to the difference in these materials: this mixture constitutes vinegar. Its sour taste, however, is derived exclusively from acetic acid, which we can obtain in a separate state. Its taste is then simply, but intensely, acid(43).

A very fine vinegar is now prepared from what has been called the *pyroligneous acid.* When wood is converted into charcoal in close vessels, for the purpose of manufacturing gunpowder, if the vapour that escapes from it is condensed, it forms an extremely acid liquor, which has received the name of *pyroligneous acid:* the fluid thus procured contains tar, and several other impurities. The acid when separated from these impurities is found to be the acetic. The process of preparing it has been brought to great perfection, and a very fine vinegar is now obtained from it(44).

Caroline. There is one common fermentation which scarcely appears to belong to either of those which you have mentioned, and it certainly does not appertain to the putrefactive: I mean the fermentation of bread.

Mrs B. This at one time was called the *pannary fermentation*, and was believed to be peculiar in its character. The prevalent opinion now is that it is identical with the vinous. The yeast acting upon the fecula, produces the saccharine and vinous fermentations; carbonic acid is disengaged, which, being entangled by the dough, causes it to rise, as it is called, by filling it with numerous air bubbles, which give to it its spongy texture, or lightness. In proof of the truth of this theory, alcohol has actually been detected in dough(45).

Caroline. I believe that the *putrefactive fermentation* completes your list of these processes, and that it is the termination of the vegetable existence, completely undoing the work which organization had effected.

Mrs B. The PUTREFACTIVE FERMENTATION, although more strongly marked, and more rapid, in animal than in vegetable substances, does evidently take place in the latter. Moisture, a sufficient degree of heat, and access of air, are necessary to this process. The principal solid product is vegetable mould, which consists of carbon, combined with some oxygen and hydrogen; water, a little acetic acid, and probably some oily matter constitute the fluids; and carbonic acid and light carburetted hydrogen, the gases. But from those plants which contain nitrogen, sulphur, or phosphorus, proceed ammonia, and portions of some other compound gases, resembling those which were noticed at an early part of our last conversation, as resulting from the decay of animal matter(46).

Emily. We have traced these substances to their state of final disorganization, and it would be delightful now to follow them to their resuscitation in new forms, giving organization, life, and beauty to other vegetable beings, of which they are prepared to become the nutriment.

Mrs B. This would certainly be a most worthy object of inquiry; but

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42. Relate the circumstances attendant on this fermentation.
43. In what consists the difference between *vinegar* and *acetic acid?*
44. How is *pyroligneous acid* procured, and what is its nature?
45. What is observed respecting the *fermentation of dough?*
46. What are the general products of the putrefactive fermentation?

it belongs to the department of *vegetable physiology*, rather than to that of chemistry. This subject has been so ably and agreeably treated by Mrs Marcet in her "Conversations on Vegetable Physiology," that I can promise you equal pleasure and advantage from a careful perusal and study of that work.

CONVERSATION XXX.

ON ANIMAL CHEMISTRY.

The Constituent Principles of Animal Matter found in Vegetables. Their Proximate Principles more Complex. Fibrin. Albumen. Fining of Wine, Coffee, &c. Gelatin, Glue, and Icthyocolla. Osmazome. Process of Tanning. Acids existing in the Animal System. Animal Oils and Fats. Stearine and Elaine. Margaric and Oleic Acids. Glycerine. Adipocere. Formation of Oils from their Constituents. Milk, Cream, Casseous Matter or Curd, Whey, and Rennet.

Mrs B. We have now, young ladies, arrived at the last division of our subject, ANIMAL CHEMISTRY. In this department are comprehended the most complex and wonderful of all the Creator's works. The proximate principles found in the beings which form this kingdom, although less numerous than those of vegetables, are still more dependent upon the control of that mysterious principle, life; as the large quantity of nitrogen which most of them contain, gives them a constant tendency to undergo the putrefactive fermentation, in which those extremely offensive gases are disengaged which distinguish the rapid decay of animal matter(1).

Emily. As all animals ultimately derive their nourishment from vegetables, it seems strange that they should be more complex in their composition than the substances upon which they depend for sustenance.

Mrs B. All the constituent materials of the animal economy have actually been discovered in certain vegetables. Nitrogen exists in wheat, and in many other plants. But animals are surrounded by an atmosphere in which this principle abounds, and from which they might obtain it were it entirely absent from their food(2). Besides the oxygen, hydrogen, carbon, and nitrogen which animal substances contain, sulphur, phosphorus, iron, lime, and other earthy as well as saline ingredients are found in them, in notable, and sometimes in very considerable quantities. Each of them also has been discovered in certain plants. It is in the proportionate quantities, and the mode of combination, therefore, that the difference between animal and vegetable products principally consists(3).

Caroline. I am glad that the proximate principles of animal matter, although more complex, are not equally numerous with those of vegetables, as we may the more readily become acquainted with them.

Mrs B. The first of the animal products which I shall describe is FIBRIN. This constitutes the principal part of the flesh, or muscles, and is contained also in large quantities in the blood. Fibrin may be obtained by digesting lean meat in successive portions of water until all the colouring

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1. In what do the animal principles differ from those of vegetables?
2. What are the sources from which animals may derive their constituents?
3. What further is remarked respecting these combinations?

matter is discharged, and the soluble portion dissolved(4). It then appear as a white, fibrous substance, which is insipid, inodorous, and insoluble i water at common temperatures.

Fibrin when moist possesses some elasticity, but when dried it become hard, brittle, and semi-transparent. If allowed to remain in a moist stat it soon putrefies, especially in warm weather(5).

Caroline. As fibrin is the basis of the muscles, it must be among th most abundant of the animal principles.

Mrs B. It is so; but there are two others, *albumen* and *gelatine*, which are found in most parts of the system, although in smaller quantities than fibrin.

ALBUMEN may be seen, in a form almost pure, in the white of an egg. The *serum*, or white part, of the blood also contains a large portion of it, and the same may be said of the fluid which serves to lubricate the joints. In these instances it exists in the fluid state; but it also forms a part of many of the solids, such as the skin, and the membranous coating of the various vessels. Its most distinguishing property is its coagulating when heated; and a similar change is produced in it by the action of acids, of alcohol, and of some other agents(6).

Emily. This coagulation by heat is familiar to us in the white of the egg, which, unlike most other substances, becomes harder by boiling.

Mrs B. Albumen, when pure, coagulates at a temperature of one hundred and sixty degrees, and when diluted with water it undergoes the same change at the boiling point. Even when mixed with one thousand times its weight of water, the temperature of two hundred and twelve degrees will render the water milky and opake(7).

Emily. I suppose, then, it must be this property of coagulating which, in some way, causes the white of the egg to clear coffee and other liquids.

Mrs B. It is. When the white of an egg is mixed with coffee, it coagulates by boiling; this renders it insoluble, in consequence of which it falls to the bottom, entangling and carrying down with it, those minute particles which would otherwise render the liquid turbid. Albumen is mixed with wine for a similar purpose. The acid and the alcohol contained in the wine, conspire in producing the same kind of coagulation, and in this way the wine is fined or rendered clear(8).

Caroline. I have often observed the peculiar effect produced upon a silver spoon, when left standing in a boiled egg; it becomes not only tarnished, but sometimes almost black. In what way can albumen produce such an effect?

Mrs B. Albumen, as found in the white of the egg, contains a small portion of sulphur, which, when the egg is boiled, unites to hydrogen, and produces sulphuretted hydrogen in sufficient quantity to produce the effect of which you speak. Silver and some other metals are attacked and blackened by this gas(9).

The third of these most prevalent animal compounds, is GELATINE, or JELLY. This is the chief ingredient of the skin, and it is largely contained also in the cartilages, tendons, membranes, and bones. From these substances boiling water separates and dissolves it. The solution, thus obtained, becomes more or less solid, on being allowed to cool, and receives the

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4. What is *fibrin*, and how may it be separately obtained?
5. By what properties is it distinguished?
6. In what substances is *albumen* found, and what are its properties?
7. At what temperature does albumen coagulate?
8. How does it operate in clearing coffee, and in fining wine?
9. From what cause does an egg blacken a silver spoon?

names of *glue*, *size*, or *jelly*, according to its consistence, and the purpose to which we design to apply it(10).

Caroline. But surely common glue, and calves' foot jelly are not exactly the same substance.

Mrs B. Their property of forming a jelly when cold depends entirely upon the presence of the same principle, gelatine. Glue is made by boiling the ears, feet, and refuse cuttings of the skins of animals in water, and evaporating the fluid to such an extent, that, on cooling, it should form a very hard jelly. This is afterwards cut into slices, and dried on netting stretched upon frames. The only difference between this and the jelly from calves' feet, or from isinglass, is the freedom of the latter substances from the impurities which accompany the former(11).

Emily. I have understood that *isinglass*, which is sometimes called *fish glue*, is furnished by some species of sturgeon, but from what part of the fish, I do not recollect.

Mrs B. Its most proper name is *ichthyocolla*. It consists of the membranous sounds of several fishes of the sturgeon kind, and being a very pure species of gelatine, it is frequently employed where culinary preparations of jelly are required(12).

The horns and hoofs of all animals yield a considerable quantity of gelatine; the earthy matter of the bones is completely penetrated by it. When such substances are boiled in water, especially after being reduced into small fragments, or shavings, the gelatine is separated from them, in consequence of its great solubility(13).

Caroline. Does not the nutritious property of soup depend entirely upon the gelatine which it contains? Rich soup, I have observed, always forms a jelly when it is cold.

Mrs B. All the soluble parts of the flesh and bones, used in the making of soup, are contained in it, and the portion of gelatine is usually considerable; but pure gelatine is without taste or smell, and you would not speak very highly of soup which resembled it in these particulars. The characteristic taste and odour of soup depend upon the presence of a peculiar principle which is called OSMAZOME. This is a soluble substance of a yellowish brown colour, and which has no tendency to solidify when cold(14).

Emily. We must not forget that the explanation of one of the important properties of *tannin*, was deferred until we had acquired some knowledge of gelatine.

Mrs B. I am gratified at your reminding me of this fact. You are aware that the conversion of the skins of animals into leather, is performed by a process called tanning. In this process a chemical union is formed between the *tannin* which is contained in the bark of certain trees, (particularly that of the oaks), and the gelatine which forms the principal ingredient in the skins of animals(15).

Emily. Pray how is this operation performed?

Mrs B. After the removal of the hair, the skin is exposed to the action of a solution of *tannin*, derived from substances containing considerable quantities of this principle, and which are disposed to yield it readily. The usual method is to infuse coarsely powdered oak bark in water, and to keep the

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10. In what parts is *gelatine* contained, and what property distinguishes it?
11. From what is common glue made, and how is it manufactured?
12. What is *icthyocolla*, and from what animals is it procured?
13. From what other parts of animals may gelatine be obtained?
14. From what substance are the odour and flavour of soup derived?
15. In what does the process called *tanning* consist?

skin immersed in this infusion for a certain length of time(16). During the performance of this process, which is slow and gradual, the skin is found to increase in weight, to acquire considerable tenacity, and to become nearly impermeable to water. The effect may be much accelerated by using solutions strongly saturated with the tanning principle, (which can be extracted from bark), instead of employing the bark itself. But this quick mode of preparation does not appear to make leather equally good with that obtained more slowly(17).

Caroline. Then the effect of *tannin*, upon the skins of animals, is to render their gelatine insoluble in water?

Mrs B. Such is the change produced, and you have in this case an example of the combination of two soluble substances, tannin and gelatine, uniting together, and forming an insoluble material, leather(18).

Caroline. I wish the chemist had found some other name for tannin; it so closely resembles that of the process of tanning, that I have always to pause in order to ascertain which of the two is the subject of remark, the effect produced, or one of the agents necessary to its production.

Emily. If leather consists of tannin, combined with glue, might it not be manufactured by mixing these two materials together?

Mrs B. I have in one of these glasses an infusion of gall nuts, which consists in great part of tannin, and in the other, some glue diffused in water; I will pour these together, that you may observe the effect produced.

Caroline. What a copious precipitation! How readily you have converted the two into leather(19).

Mrs B. Chemically speaking the compound is leather; but then it is leather divided into minute particles. Were we to press these particles together, we might form them into a sheet like paper; but even then it would possess little tenacity, as it would not have the fibrous structure of the organized skin, which is necessary to give to leather that toughness and strength without which it would be of no value(20).

An infusion of gall nuts is so delicate a test for gelatine, as to precipitate it although the gelatine may be mixed with five thousand times its own weight of water(21). We must now dismiss gelatine and examine some other of the animal compounds.

Emily. We frequently hear of acidity in the animal system; there is, therefore, I suppose, a class of *animal acids*. All the simple substances which exist in vegetables, are found in animal matter also, and are likely therefore to form analogous combinations.

Mrs B. Portions of the sulphuric, phosphoric, muriatic, and acetic acids, are found in the animal system; but it also contains others which belong exclusively to it(22). Like the general animal products, however, the animal acids are fewer in number than those found in vegetables; nor are they of equal importance. Acids are not unfrequently the products of diseased action, or of the decomposition of animal substances: they, however, are not of a nature to require our attention(23). The most remarkable of the acids belonging to the animal kingdom, are those which

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16. What is the method usually pursued by the tanner?
17. What changes occur in the skin, and is the operation rapid?
18. What is exemplified by the union of *tannin* and *gelatine?*
19. What experiment is mentioned of mixing two infusions?
20. What is remarked respecting the substance produced?
21. What is mentioned respecting the infusion of gall nuts as a test?
22. What acids are found existing in animals?
23. What is remarked respecting some other acids?

exist in the *animal oils* and *fats*, or which are formed by them when they are converted into soap, or submitted to other chemical processes.

Caroline. Although I know that the animal oils combine with alkalies, and thus exhibit one of the characteristic properties of acids, still they are among the last of the animal products in which I should have looked for them(24).

Mrs B. You will presently find that the combinations to which you have alluded are actually those of acids and alkalies, and that soap, therefore, strictly speaking, may be placed among the salts.

The ANIMAL OILS and FATS do not contain nitrogen, and are nearly identical in their composition with the fixed vegetable oils; the same ultimate principles, carbon, hydrogen, and oxygen being the constituents of both. They also answer equally well for the purpose of giving light, the manufacture of soap, and the other uses to which such substances are applied(25).

Emily. But, Mrs B., there must be some great difference between the composition of oils, and such fats as suet; the former are fluids, and the latter solids.

Mrs B. The fixed oils and fats are not pure proximate principles, but consist of two distinct substances, one of which at common temperatures is solid, whilst the other is fluid. The former is called STEARINE, the latter ELAINE(26). The more solid fats, such as suet, consist principally of *stearine*, whilst the more fluid of the oils are almost wholly *elaine*. Those which are intermediate in consistency, are so in consequence of the proportionate quantity of these principles contained in them(27).

Emily. That accounts very satisfactorily indeed for the different degrees of hardness in these substances, but you have intimated that the oils and fats, if not actually acids, are capable of becoming such.

Mrs B. It has been discovered that when these fatty matters are combined with alkalies to form soap, a new arrangement of their elements takes place, two acids being formed, one of which is called *margaric* and the other *oleic acid:* both of these combine with the alkali, and thus produce soap(28). During the process, a third principle is separated from them which has received the name of *glycerine*. This is a transparent liquid, which is inflammable, has neither taste or odour, and, unlike the oils, is soluble in water(29).

Caroline. The margaric and oleic acids, you have told us, exist in combination with the alkali, when soap is formed; but still they must be separable from each other, or their distinct natures could not have been known.

Mrs B. Soap made with potash may be considered as an *oleate* and *margarate* of that alkali: these acids can be separated from each other by means of alcohol, one of them being soluble, and the other insoluble, in that fluid(30). The *margaric acid*, when obtained alone, is a brilliant white solid, of a pearly lustre and crystalline texture. It has an appearance somewhat like that of spermaceti, but more beautiful. Manufactories have been established for procuring it from lard, and excellent candles are made from it(31).

Oleic acid is a colourless, oily fluid, which does not congeal until its temperature is reduced nearly to zero. In the conversion of suet into soap,

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24. What animal substances is it said assume the acid form?
25. What is observed respecting the animal *oils* and *fats?*
26. Of what two principles do the different oils and fats consist?
27. For what circumstance respecting them does this account?
28. What is observed respecting the formation of two acids?
29. What third principle do the fats contain?
30. What is said of the separability of *margaric* and *oleic acids?*
31. What are the appearance and use of margaric acid?

a third acid, called *stearic*, has also been detected; it bears a strong resemblance to the margaric(32).

Caroline. In the progress of discovery it seems likely that the chemists will make the catalogues of animal acids and of the other animal products, as extensive as those of vegetables.

Mrs B. There is reason to believe that other acids are actually generated from different kinds of fat, in the process of *saponification*, or conversion into soap; but these are not to be confounded with those principles which exist ready formed in the living system(33).

Emily. I have read of the conversion of animal muscle into a substance which has some resemblance to spermaceti; a change said to be produced by the influence of water.

Mrs B. Such a change does actually take place when fresh muscle is exposed to the action of water, or of moist earth. The substance so produced has been called *adipocire*(34). Chemists, however, are not agreed as respects its nature; some think it a real conversion of fibrin into adipocire; others contend that the fibrin is merely removed from the fatty matter which originally accompanied it; and others, again, that the substance obtained is a species of soap, containing a considerable portion of margaric acid(35).

Caroline. As some of the proximate principles contained in vegetables, are capable of being transformed into others of the same class, there appears no good reason to conclude that the same may not be the case to a much greater extent than is now known. Why may not oils and fats, therefore, be produced by a new arrangement of the particles of those substances which contain their constituents?

Mrs B. Thus to produce them is certainly not beyond the probable triumph of the chemical arts; indeed it appears that substances resembling oil have actually been generated by causing the bases of certain gases which contain its constituents, to combine together(36).

Bérard, a French chemist, mixed together carbonic acid, hydrogen, and carburetted hydrogen, which he passed through a red hot tube, and obtained a white crystalline substance, having the general properties of spermaceti. In the hands of another chemist a similar result followed from a mixture of coal gas, and aqueous vapour(37).

Emily. Both stearine and elaine must enter into the composition of *milk*, as we are furnished with butter from the cream contained in it. There must, however, be several other principles besides these in this liquid.

Mrs B. Milk, as it was designed by the great Author of our existence to be, for awhile, the sole nourishment of animal nurslings, consists of those ingredients which are most easily digested and assimilated. Its most abundant principles are *cream*, *caseous matter* or curd, and *whey*(38). In these are also contained a saccharine substance, called *sugar of milk; muriate* and *phosphate of potassa; phosphate of lime; acetic acid; acetate of potassa;* and a trace of *acetate of iron.* All the substances, therefore, which are required to form the solid and the fluid parts of the growing animal, are contained in this single fluid(39).

Caroline. The three principal constituents of milk appear to be very

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32. What of oleic acid, and what is said of stearic acid?
33. What general remarks are made respecting such acids?
34. In what way is the substance called *adipocire* formed?
35. What different opinions have been entertained respecting it?
36. What is observed on the possibility of forming certain bodies?
37. What examples are given of the forming of oils?
8. What are the principal substances in *milk?*
What other articles have been detected in this fluid?

loosely combined; as the cream rises spontaneously to the surface, and the curd and whey will afterwards separate from each other if the milk is allowed to become sour, or if a little rennet is poured into it(40).

Mrs B. Such is the fact: this separation, however, is by no means a perfect one. When the cream rises, it carries with it a portion of the caseous matter and of the whey, which, in the process of churning, separate in the form of buttermilk(41). The curd also retains a small portion of the cream. When milk is intended to be made into cheese, no part of the cream should be separated. Good cheese is, consequently, rarely produced in those dairies where much butter is made; the former being robbed for the sake of the latter(42).

Caroline. What is rennet, and how does it operate in causing the curd to separate from the whey?

Mrs B. *Rennet* is made by infusing in hot water the inner coat of the stomach of a calf: its peculiar property is derived from the *gastric juice*, of which we shall speak hereafter(43). Either rennet, or acids, will produce the coagulation of the curd, but their mode of operation is not well understood. When this coagulation is effected in new milk, the cream is entangled with the caseous matter, and a rich cheese may be made from it; but the curd, alone, produces a cheese which is altogether unfit to be used as an article of food(44).

Emily. Curd, then, as usually obtained, is not pure caseous matter.

Mrs B. By no means. To procure pure *caseous matter*, it must be obtained from skimmed milk, and be well washed with water. It is then white, insipid, and inodorous, and bears a considerable resemblance to albumen, although it is by no means the same substance(45).

Caroline. The organs of digestion and secretion may well prepare and appropriate the various substances required for the nourishment of the system from an article so well adapted to this purpose as milk. But it appears really surprising that the delicate machinery intended for these purposes is not totally deranged and destroyed by the various heterogeneous and indigestible compounds with which luxury and fashion induce us to pamper our appetite.

Mrs B. The process of digestion; some inquiries into the nature of the blood; the operation of respiration, and the production of animal heat, will form the principal topics of our next, and last, conversation. I, however, shall then direct your attention to some other particulars which have hitherto been but slightly noticed.

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40. What proves that the cream, whey, and curd, are loosely combined?
41. Does this separation appear to be a perfect one?
42. What is remarked respecting the making of good cheese?
43. How is the *rennet* obtained which is used for coagulating milk?
44 What further remarks are made on the coagulation of milk?
45. How may pure *caseous matter*, or *curd*, be procured?

CONVERSATION XXXI.

ON DIGESTION, SECRETION, ANIMAL HEAT, &c.

Formation of Chyme and Chyle. Bile, its Secretion and Use. The Gastric Juice. Its remarkable Solvent Power. Circulation of the Blood. Arterial and Venous Blood. Change produced in the Blood by Respiration. Priestley's Experiments on the Effects of Oxygen on Venous Blood. Permeability of Membranes. Carbonic Acid exhaled from the Lungs. Animal Heat influenced by Respiration. Conclusion.

Mrs B. We are to commence to-day with the PROCESS OF DIGESTION, which is, necessarily, the first step towards *nutrition.* This process is performed in the stomach, and is effected principally by the agency of the gastric juice, a fluid secreted in that organ. Other fluids, which are supplied from other sources, however, lend their aid in carrying on this operation(1).

The food is intimately mixed in the stomach with these juices, is dissolved and converted into a semi-fluid, pulpy mass, which is denominated CHYME. It is from this mass that the *absorbent vessels,* called the *lacteals,* select those particles which are destined to nourish the whole system(2).

Caroline. And how do these *lacteal vessels* operate in making this selection?

Mrs B. That is a question which I cannot answer, and for reasons which on a moment's reflection must be apparent to you. We know however that after the chyme has been prepared by the gastric juice, these lacteal absorbents, which are situated in that part of the intestinal canal which the *chyme* first enters, obtain from it a white opake fluid, to which the name of *chyle* has been appropriated(3).

CHYLE, when fresh, possesses an appearance much resembling milk. Its taste is sweetish, and at the same time somewhat saline. After exposure for a few minutes to the air, it coagulates, and eventually separates into a solid mass, and a limpid fluid much like the serum of the blood(4).

Emily. This chyle must, of course, like milk, contain all the ingredients necessary to the nourishment of the body; but in what way do the lacteals dispose of it?

Mrs B. It is conveyed by them into a tube which is named the *thoracic duct;* and by this it is carried into a large vein, called the *subclavian vein,* where it mixes with the blood, and is itself soon converted into that fluid(5). It is from the blood, that all the materials are supplied which support the growth, or supply the waste, of the system in all its parts, whether fluid or solid(6).

Emily. How numerous must be the absorbent vessels, and how various and distinct their offices! Well indeed might David say that "we are fearfully and wonderfully made." Are these various secretions to be attributed to chemical affinity, or to some mysterious mechanical filtration?

Mrs B. In many parts of the body, numbers of small vessels are collected together in little bundles, which are called *glands,* from a Latin word,

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1. What is observed respecting the process of digestion?
2. What is the first change produced in the food?
3. What is the office of the *lacteals,* and how are they situated?
4. What are the characteristics of the fluid called *chyle?*
5. How is the chyle conveyed, and into what is it converted?
6. From what does the system derive its nutriment?

meaning an *acorn*, as some of them are thought to resemble that fruit in their form. The office of the glands is to *secrete*, or separate, certain matters from the blood(7).

The animal principles are not separated from the blood by mere mechanical filtration, but are chemically produced. The substances thus formed are not contained in the blood, although their constituents exist in that fluid. The secretions are of two kinds; those which consist of peculiar animal fluids, as *bile*, *tears*, *saliva*, &c.; and those which form the general materials of the animal system, for the purpose of recruiting and nourishing the several organs of the body; such as *albumen*, *gelatine*, and *fibrin:* the latter have sometimes been distinguished by the name of *nutritive secretions*(8).

Caroline. I am quite astonished to hear that all the secretions should be derived from the blood. I thought that the *bile* was produced by the liver.

Mrs B. So it is; but the liver is nothing more than a very large gland, which secretes the bile from the blood(9).

Caroline. *Bile* must answer some useful purpose, or so large a gland would not be provided for its secretion; yet it appears to be a frequent cause of disease. This, I suppose, arises from its excess.

Mrs B. With the uses of BILE, we are not very well acquainted; but it appears to act an essential part in the conversion of chyme into chyle, and to operate as a general stimulus to the intestinal canal. When the secretion of bile is arrested, or its passage into the intestines obstructed, those diseases are produced which fully indicate the importance of this fluid to our well being(10).

Caroline. The *gastric juice*, which is contained in the stomach, and of which you have spoken as the main agent in producing the solution of the food, is one of which we are anxious to learn something further. This fluid must be a most powerful solvent.

Mrs B. The sensible properties of the GASTRIC JUICE, would never have led us to the inference that it possessed any extraordinary solvent power. When obtained from the stomach, it is a transparent fluid, the taste of which is slightly saline, without any indication of the possession either of acid or alkaline properties. During the period when the process of digestion is going on, however, free muriatic acid may be detected in it(11).

Emily. It appears most astonishing that such a fluid should act with the power it does upon solid animal and vegetable matter; but may it not, in fact, be greatly aided by some mechanical action of the stomach itself?

Mrs B. Although the gastric juice is, in appearance, as simple a fluid as saliva, its solvent power is a fact most satisfactorily established. Meat, and other alimentary substances, mixed with it and kept at about the temperature of the body, are entirely dissolved by it. To prove that in the living animal, the solution of the food is altogether a chemical process, such substances as are usually eaten have been enclosed in tubes or balls of silver, perforated with holes: these have been swallowed, and the contained materials have been as completely acted upon, as when eaten in the usual way(12). The gastric juice is powerfully antiseptic; not only preserving flesh which is immersed in it, but actually removing the taint from that in which putrefaction had commenced(13).

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7. What is said of the *glands* and their office?
8. What remarks are made on their mechanical and chemical action?
9. What is the liver, and what fluid is secreted by it?
10. What is said respecting the uses of the *bile?*
11. What is first remarked respecting the *gastric juice?*
12. What proof is given of its extraordinary solvent power?
13. What other remarkable property is possessed by it?

Caroline. An alchemist, who boasted that he had discovered the universal solvent, was asked in what vessel he could keep it. May we not with equal propriety inquire how this universal solvent of animal substances can be contained in the stomach, which is itself an animal organ(14)!

Mrs B. This circumstance affords one of the most remarkable evidences of the controlling power of the living principle, which, during the existence of the animal enables it to resist the operation of this active agent upon the coats of the stomach. It is a fact, which has been well ascertained, that, after death, the gastric juice begins immediately to operate upon this organ, and dissolves it as it would other animal matter(15).

Emily. With all his acquirements and discoveries, how limited is the power of man! How perpetually he fails even in the attempt to imitate some of those compounds with the constitution of which he has become familiarly acquainted! Yet, by the hand of nature they appear to be formed almost without an effort.

Mrs B. We have traced the nutritious part of our food through the lacteals into the thoracic duct, and thence into a vein called the subclavian, in which it mixes with the general mass of the blood(16). Neither the time which we have to devote to the inquiry, nor the state of your anatomical knowledge, will admit of a very minute examination of the circumstances connected with the passage of this fluid through the veins and arteries; nor indeed does this inquiry properly belong to the province of the chemist.

You have frequently heard of the CIRCULATION OF THE BLOOD; tell me, Caroline, in what you understand this process to consist.

Caroline. The idea that I have of the circulation of the blood, is, that it runs from the heart as its fountain, through all the veins of the body, and is by them carried back again to the heart. I do not pretend, however, to any knowledge upon this subject, as it is one into which I have never inquired.

Emily. There must be something more in the circulation than you mention, as the blood runs through arteries, as well as through veins, and although, like yourself, I have but little information concerning anatomy, yet I know that there is a difference between the blood in the arteries, and that in the veins.

Mrs B. The heart is a strong muscular bag, possessing the power of alternately expanding and contracting, by which operation it first receives the venous blood into its cavities, and then forces it out again, in order to keep up its circulation. The arteries are vessels which receive the blood directly from the heart, and convey it to all the extremities of the body. Those into which the blood is forced, are large, but they form numerous branches in their course, and terminate in a countless number of extremely minute tubes. From these, the blood is received by the veins, which conduct it back again to the heart(17).

Caroline. Pray in what respect does the blood differ in these two sets of vessels, which appear so similar, and so evidently contribute to the same end?

Mrs B. Whilst circulating through the arteries, the blood is of a florid red colour, but in the veins its hue is that of a very dark purple. You are already informed that the different glands secrete the solids and fluids which are required for the support and supply of the whole system. These secretions are all effected during the passage of the blood through the arteries, and it is thus deprived of a large portion of those principles which are necessary to the carrying on of the animal functions. This reduces it to the

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14. What question is asked respecting the gastric juice?
15. What observations are made in reply to this question?
16. Repeat what has been said on the first formation of the blood.
17. In what way is the circulation of the blood carried on?

state in which it exists in the veins, through which it is returned to have its power renewed(18).

Caroline. This renewal, I suppose, is principally effected by the fresh supply which it receives from the thoracic duct; but that does not appear to me to account in the least for the great change which takes place in its colour.

Mrs B. The change in the colour of the blood is produced in the act of respiration, of which I shall speak presently, but I will first give you some information respecting the composition of this vital fluid(19).

Blood, when first drawn, appears to the naked eye to be a homogeneous fluid; but if examined by the microscope, it is seen to consist of numerous little red globules, floating in a colourless liquid. In a short space of time its compound nature is rendered perfectly visible, as it soon separates into two distinct parts; one, a yellowish transparent fluid, called the *serum;* the other, a red mass, known by the name of the *clot*, or *crassamentum*(20).

Emily. You spoke of the serum in our last conversation, and mentioned its containing a large quantity of albumen. From the abundance of this principle, it will, of course, become solid, if considerably heated.

Mrs B. I noticed the use of albumen in clarifying different liquids. In consequence of its containing so much of this principle, the serum from the blood of animals has been extensively employed in the refining of sugar. The chemist; however, has discovered modes of completing this process without the use of serum, and there are now many manufactories in which it is altogether rejected(21).

Caroline. I am very glad of that, for the idea of the use of blood in the making of loaf sugar, was never one of the most agreeable associations.

Mrs B. Besides albumen, the serum contains water, salts of soda and potassa, some earthy phosphates, and other ingredients. The muriatic salts are sufficient in quantity to communicate to it a sensibly saline taste(22).

The *crassamentum*, or *clot*, is more completely animalized than the serum, its principal constituent being fibrin, which is identical in its composition with that which constitutes the basis of the muscles. The colouring matter may be washed out from the red clot, and the fibrin obtained in a separate state(23).

Emily. Upon what particular substance does the red colour of the blood appear to depend.

Mrs B. This is a point which has been much disputed, and cannot yet be considered as well settled. It is believed, however, to result, principally, from the presence of iron. The existence of this substance in the colouring matter of the blood, was long ago detected; and the fact has been confirmed by recent experiments. Its quantity is minuté, but as it is contained in the colouring matter only, the inference appears to be a fair one, that it is essentially the colouring ingredient(24).

Caroline. As the bones consist of phosphate of lime, I should have looked for the presence of this earth in the blood; for otherwise the secreting vessels which are destined to nourish those solid pillars of the body, could not obtain their supply. But although the poets have imagined that there might be a flow of "iron tears down Pluto's cheeks," I never expected to

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18. What is observed respecting arterial and venous blood?
19. In what operation of the system is the change in its colour produced?
20. What is said of the first appearance and the separation of blood?
21. What is observed of the use of *serum* in refining sugar?
22. What substances are enumerated as contained in the blood?
23. What is said respecting the *crassamentum*, or *clot?*
24. Upon what substance does the colour of the blood appear to depend?

learn the philosophical truth that a current of iron was actually coursing its way through every part of the body.

Emily. By what particular operation of the system is the venous, changed into arterial blood? The transformation appears to be performed with great rapidity, as it arrives at the heart in the former state, and leaves it in the latter.

Mrs B. The process of RESPIRATION will lend us some aid in accounting for this change, as it appears evidently to take place in the lungs. After the blood has performed its function of nourishing the body, it is returned into one of the cavities of the heart, called its *right ventricle:* this, by its muscular power, contracts, and throws the fluid through a large vessel into the lungs, which are contiguous. It circulates through this organ by means of vessels inconceivably numerous, and of a very delicate texture, where it is exposed to the action of the air which is inhaled at every breath. The oxygen of the air acts upon the blood, in a way that deprives it of its dark colour, and gives to it the florid hue, and other properties which it possesses in the arteries(25).

Caroline. But how is this possible? Whilst the air and the blood are completely separated from each other by a membrane, they cannot possibly come into contact with each other(26).

Mrs B. Your objection is one which any person unacquainted with the facts of the case might fairly urge. Dr Priestley first observed that the red colour which is so soon produced upon the surface of the blood drawn from the veins, resulted from the action of the oxygen contained in the atmosphere; and he ascertained that when kept from contact with this gas, it retained its dark colour. Upon enclosing a portion of blood in a bladder, he found that the same change was effected, notwithstanding the intervention of the membrane between the fluid, and the oxygen of the air(27).

Emily. That is a very extraordinary circumstance. If air can pass through bladders, how can hydrogen or other gases be retained in them in a state of purity for chemical experiments?

Mrs B. This in fact cannot be done. If a bladder is inflated by hydrogen, a double process immediately commences; a portion of this gas passes through, and escapes, whilst its place is supplied by the passage of atmospheric air inwards. The bladder, therefore, will still remain full, but it will soon contain a mixture of hydrogen and atmospheric air. Carbonic acid, and other gases penetrate such membranes with considerable facility, one air passing out and another in. The gases pass through with different degrees of facility; and it is a fact that a bladder partially filled with one kind of air, and exposed on its outside to a gas more penetrative than the former, will become completely inflated, and, if not very strong, will burst spontaneously(28).

Caroline. My objection is indeed answered in a very satisfactory manner, and a most remarkable fact at the same time made known to us, which but for the evidence of experiment could scarcely obtain credence.

Mrs B. This penetrability of membranes is intimately connected with the effects of respiration. We inhale atmospheric air, and when this is discharged from the lungs, it contains about one-twelfth part of carbonic acid. A portion of the oxygen of the air has disappeared, and is replaced by a corresponding portion of fixed air. As this occurs, the venous is

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25. What further is said of its circulation and change of colour?
26. What objection is urged against the action of the air on the blood?
27. In what way is this objection obviated?
28. What information is given respecting the penetrativeness of membranes by gases?

changed into arterial blood(29). It appears therefore that the dark hue of the former arises from its containing a quantity of carbon, which, combining with the oxygen of the air, becomes carbonic acid, and is thus expelled with the breath. The blood, relieved from its superabundance of carbon, assumes a florid hue, and becomes arterial(30).

Emily. This theory of respiration is to me equally gratifying and novel. I most sincerely regret that my want of anatomical knowledge interferes with that full comprehension of the subject to which an intimate acquaintance with the animal structure is manifestly necessary.

Mrs B. When the blood has been thus arterialized in the lungs, it is collected into vessels which convey it into the left ventricle of the heart. Thence it is propelled through all the different parts of the body; the large artery which first receives it, ramifying, as I have already told you, throughout the whole frame(31).

Caroline. But whence proceeds the carbon with which the venous blood becomes loaded? I do not perceive that the theory, in any way, accounts for its presence.

Mrs B. Carbon exists in greater quantity in the blood, than it does in the organized parts of the system. The arterial blood, as it supplies the various secretions, parts with a larger proportionate quantity of its other constituents, than it does of its carbon. It is in consequence of its own decomposition, therefore, and not from its acquiring any carbon as it passes through the arteries, that the blood becomes loaded with it(32).

Emily. Were it not for the perpetuity of the operation, the small quantity of carbon given out with the breath would seem to be inadequate to the decarbonization of the blood.

Mrs B. The quantity which escapes in this way is really very large. It has been calculated that the carbonic acid which is expelled from the lungs in the course of twenty-four hours, actually contains eleven ounces of solid carbon; but from an estimation of the quantity contained in our ordinary food, it would scarcely seem possible that such a portion can be exhaled with the breath(33).

Caroline. This combination of oxygen with carbon, and the consequent production of carbonic acid, render the process of respiration very similar to that of combustion; a process which would be attended with some inconvenience were it really to take place in the lungs(34).

Mrs B. The analogy of which you speak does certainly exist, and the theory of the production of ANIMAL HEAT, which has been most generally admitted as true by the chemist, has its foundation in the existence of such a process(35).

Caroline. But if animal heat were kept up from this cause, I should look for a corresponding portion of light to be disengaged; besides, would not the lungs be hotter than any other part of the body?

Mrs B. When the combination of oxygen and carbon takes place so slowly that the heat disengaged is not intense, there is no perceptible light. The advocates of this theory have attempted to prove that the capacity for heat, possessed by arterial, considerably exceeds that possessed by venous blood; and that the heat which is disengaged by the union of the carbon and the oxygen, goes to satisfy this increased capacity, and does not

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29. What change takes place in the air which we respire?
30. How does this appear to operate in changing the colour of the blood?
31. After it is arterialized, what then takes place?
32. In what way does venous blood become charged with carbon?
33. What estimate has been made of the quantity of carbon exhaled?
34. What similarity exists between respiration and combustion?
35. How has this been thought to be connected with *animal heat?*

therefore, increase the temperature of the lungs. The blood, as it supplies the various secretions in every part of the body, gradually returns to the state of venous blood; and as it does so, the heat which went to satisfy the increased capacity, becomes free, and is thus diffused(36).

Emily. This theory seems altogether to remove the difficulty which at first appeared to me insurmountable, and applies the principles of chemistry, in a very happy manner, to the explanation of one of the most interesting phenomena of the animal economy.

Mrs B. You must not, however, receive this theory as incontestably proved. Some eminent experimenters have denied the truth of the main fact upon which it is founded, and have asserted that arterial and venous blood differ but very little in their capacity for heat. It has been calculated also, that the quantity of heat given out by the body, very considerably transcends that which would be produced by the combination of the carbon and oxygen in respiration(37).

Caroline. I am sorry that the superstructure, which I at first thought so beautiful, stands upon a foundation so insecure; but perhaps you are prepared to account satisfactorily for the fact you mention.

Mrs B. There has not been a theory proposed to account for it, which is not liable to very strong objections. It is a subject which the chemists and physiologists are pursuing with great ardour, and respecting which there is much to learn. That respiration and the absorption of oxygen are intimately concerned in the phenomenon is fairly inferred from the fact that the heat in different animals is proportioned to the quantity of oxygen which they consume. It is certain, however, that other functions, such as the secretions which are going on in every part of the body, are accompanied with a disengagement of heat. It is not to chemistry alone that we are to look for an illustration of the point in question; the production of animal heat is a process of vitality, and probably will never be perfectly understood, as the nature of life itself is one of those mysteries which it belongs to the Creator alone fully to comprehend(38).

Emily. The heat of the blood is marked on the thermometer at ninety-eight degrees. Must not the temperature of the body vary with that of the atmosphere, with the gentleness or violence of our exercise, and other circumstances?

Mrs B. All these circumstances make but little difference in the temperature of our bodies, unless we judge by the surface only. A thermometer held in the mouth of a person in health, would scarcely vary a single degree, whether it were tried in summer or in winter, in the frigid or in the torrid zone(39).

Caroline. But certainly when I run fast, or otherwise use great exercise, I am warmer than at other times? Yet your remarks would lead to the conclusion that when I am overcome by the sensation of heat, I am really no warmer than when shivering with cold.

Mrs B. There is certainly a real difference in you, in the supposed cases, but the difference exists at the surface only, and it is by the surface that we judge of the sensation of heat. The animal heat is generated within the body itself, and its equality is regulated by the process of perspiration which is perpetually going on. Under ordinary circumstances this perspiration is imperceptible, yet the quantity of moisture which escapes is considerable. When exercise is taken the perspiration is quickened, and if greatly increased becomes sensible. In a healthy state it is always

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36. What difficulty is stated, and what explanation has been given?
37. What remarks are made respecting this theory?
38. What further remarks are made on the subject of animal heat?
39. What is said respecting the temperature of the human body?

proportioned to the heat generated in the body, and thus renders the excess of it latent, upon the same principle that evaporation from the earth lowers its temperature(40).

Emily. What admirable resources has nature provided for us! By the production of animal heat, she sustains our bodies at a temperature above that of the inanimate substances by which we are surrounded; and whenever its supply becomes too abundant, the excess is carried off by perspiration.

Mrs B. When they are fairly examined, and correctly estimated, we shall find all the operations of nature controlled and directed by Infinite Wisdom and Benevolence. Even in the spontaneous decay to which every thing that lives is eventually subjected, we may, instead of the work of final destruction, perceive a well ordered provision; and discover the means by which a perpetual succession of forms, resplendent with beauty, and animated by a spark from the Divinity, shall rise from the ashes of those beings which, having fulfilled the purposes of their creation, return to the elements from which they were originally produced(41).

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40. By what operation is this temperature regulated?
41. What are the concluding remarks?

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A GLOSSARY

OF SUCH TERMS AS ARE NOT FULLY EXPLAINED IN THE BODY OF THE WORK.

Aëriform. The same as elastic fluids. Having the form of air. Those which exist in this form at all common temperatures are called *permanently elastic fluids.* Steam and other vapours are *aëriform* whilst they retain the heat which converted them into that state; but they become liquids, or *non-elastic fluids*, by a reduction of their temperature.

Alcohol. The pure spirit obtained, by distillation, from liquors which have undergone the vinous fermentation. This spirit when *rectified*, so as to separate it from the peculiar juices of the fermented liquor, is the same from all. Alcohol is sometimes called *spirits of wine;* but what is sold under that name rarely deserves to be denominated alcohol. What is called *proof spirit*, contains nearly as much water as alcohol.

Animal charcoal. When animal matter is submitted to destructive distillation, the black carbonaceous matter which remains in the retort is called animal charcoal. Bones are frequently so treated for the purpose of manufacturing ammonia. The residuum, when ground, is *ivory*, or *bone, black.* This is frequently called animal charcoal; it contains, however, the earthy matter of the bones, which is phosphate of lime.

Annealing. Glass, steel, and some other substances become brittle if they are rapidly cooled after being made red-hot; whilst if cooled slowly this brittleness is in a greater or less degree prevented. This slow cooling is called annealing.

Calcareous. Lime, and those earthy minerals which contain a large portion of lime, have received the name of *calcareous earths.*

Calcination. Certain substances when changed by the action of fire are said to be calcined. The name *calx* was given to the oxide of a metal, when it was produced by the action of heat. Lime, magnesia, &c. when deprived by heat of the water and carbonic acid with which they are usually combined, are said to be calcined.

Causticity. The pure alkalies, the stronger acids, and some of the metallic salts, which destroy the texture of the flesh, are said to be caustic.

Chalybeate. Containing iron. Many mineral waters contain some salt of iron, usually a carbonate; such waters are called chalybeate waters.

Effervescence. When gaseous matter escapes rapidly from any mixture, so as to occasion an appearance resembling boiling, the liquid is said to effervesce. In active fermentations there is an effervescence; whenever a stronger acid is poured upon an alkaline carbonate, a brisk effervescence ensues from the escape of carbonic acid.

Empyreuma. That peculiar and very unpleasant odour which is produced by heating vegetable and animal matter in close vessels, is called empyreuma. If too much heat be applied in distilling vegetable substances, a disagreeable taste and odour are acquired by the spirit, which are said to arise from empyreumatic oil.

Frigorific mixtures. Those mixtures the materials of which react upon each other so as to cause freezing. The cold produced results from the dissolution of solids, which in putting on the fluid form absorb caloric.

A degree of cold much more intense than that of any known natural temperature, may be produced by such mixtures. The following table exhibits the power of some of them.

Mixtures.		*Thermometer sinks.*	*Degrees of cold produced.*
Muriate of ammonia	5 parts	From + 50° to + 4°	46
Nitrate of potash	5		
Sulphate of soda	8		
Water	16		
Sulphate of soda	3 parts	From + 50° to — 3°	53
Diluted nitric acid	2		
Snow	3 parts	From + 32° to — 23°	55
Diluted sulphuric acid	2		
Snow	2 parts	From + 32° to — 50°	82
Muriate of lime crystallized	3		
Snow	1 part	From — 40° to — 73°	33
Muriate of lime crystallized	3		
Snow	8 parts	From — 68° to — 91°	23
Diluted sulphuric acid	10		

Gasometer. An air holder, so constructed that the quantity of gas which it contains can be ascertained or measured.

Geology. That branch of science which inquires into the structure of the earth. The mineralogist ascertains the nature of the individual substances of which the earth consists; whilst the geologist studies its architecture, or the general arrangement of the larger masses of which it is composed, and their positions relative to each other.

Hydrometers. Instruments for ascertaining the specific gravities of liquids and other substances. These are described in the "Conversations on Natural Philosophy."

Hygrometers. Instruments which indicate the relative quantities of moisture contained in the atmosphere, in different places and at different times.

Hygrometric moisture. That moisture, or watery vapour, which is not in a state of combination, and which will, therefore, affect the hygrometer as free caloric will affect the thermometer.

Laboratory. A place furnished with apparatus necessary for the performance of the various operations in chemistry.

Mineralogy. That branch of science which inquires into the nature of the substances that constitute the mineral kingdom. The term mineral is derived from the mines in which the greater number of these bodies are found; but in its most extensive acceptation it includes all the substances which are inorganic; or which, in other words, do not belong to the animal or vegetable kingdoms. Those minerals which exhibit the forms of organized matter, have received these forms from such matter having been penetrated by earthy or metallic substances, which the organized bodies have thus moulded into their own peculiar shapes. Such minerals are termed *fossils*, or *organic remains.*

Mineral waters. Spring water generally contains some portion of earthy, saline, or other matter, derived from the ground through which it passes. When the quantity is considerable, and the water is much changed in its sensible properties, it then becomes a *mineral water.*

Petrifaction. Animal and vegetable substances frequently appear to be converted into stone; the external form being retained, whilst the substance is completely changed. These are called petrifactions. Some waters have the property of effecting this change with considerable rapidity; and these are called petrifying waters. (See Mineralogy.)

Phlogiston. This name was formerly given to a principle which the older chemists imagined was contained in all combustible substances. They considered *phlogiston* as the principle of inflammability, or the very essence of light and heat. It was thought that when a combustible had been burnt, it was deprived of its phlogiston, or was *dephlogisticated.* The light and heat emitted in combustion were supposed to be a consequence of the separation of the phlogiston from the burning body; and in order to render it again combustible, it was believed that the phlogiston must be restored to it. The metals, which we consider as simple bodies, were regarded as combinations of phlogiston with a simple body, different for each metal, called a *calx,* now known to be compound, and denominated a metallic oxide. When this *calx* was brought back to the metallic state by heating it with charcoal, it was believed that the phlogiston, with which the metal had parted in its combustion, was restored to it by the charcoal.

Pyrophorus. A substance which takes fire by mere exposure to the air. It is made by calcining alum and sugar, or alum and flour together. The product must be kept in a well stopped phial till wanted for use.

Quartz. The different kinds of minerals which consist almost exclusively of silex, are denominated quartz. In rock crystal the quartz is symmetrical in its form, but it is frequently found transparent, without the crystalline form. Many of the minerals of this family are opake.

Radical. A term frequently used as synonymous with the word *basis.* Sulphur is the radical of sulphurous and sulphuric acids. Carbon is the radical of carbonic acid.

Reagents. Substances employed as *tests* to discover the presence of any particular ingredient in a substance, or compound to be examined. Gallic acid is employed as a test, or reagent, to discover the presence of iron in a solution; the iron and the gallic acid *react* upon each other and produce a compound of an intense blue colour, which serves to show that the metal in question is contained in the mixture.

Semi-metal. This term is now obsolete, but it was formerly applied to those metals which are most readily oxidized, or changed, by the action of heat and air; whilst those which most powerfully resist the influence of these agents, were called perfect metals.

Thermometer. An instrument for measuring, or ascertaining, the temperature of bodies. At page 47 the different kinds of thermometers now used are described. Although Fahrenheit's, the Centigrade, and Reaumur's scales are differently divided, they may be readily compared with each other by observing the following rules.

Nine degrees of Fahrenheit's scale are equal to five of the centigrade, and to four of Reaumur's thermometer. Fahrenheit's is therefore reduced to the centigrade scale by multiplying by five, and dividing by nine; or to that of Reaumur by multiplying by four, and dividing by nine. By reversing the process either of these may be reduced to Fahrenheit's scale. But it must be recollected that Fahrenheit has fixed the zero at 32 degrees of his scale below either of the others, they having their zero at the freezing point. This number 32, must therefore be either added or subtracted, as the case may be, in comparing Fahrenheit with either of the others.

To reduce centigrade degrees to those of Fahrenheit, multiply by nine and divide by five, and to the quotient add thirty-two.

To reduce Fahrenheit's to the centigrade, subtract 32, then multiply the remainder by 5, and divide the product by 9.

The same rules answer for Reaumur's and Fahrenheit's, substituting the number 4 for the number 5, in the foregoing examples.

Vitrification. The conversion of bodies into glass, by intense degrees of heat. The earths and metallic oxides generally, are capable of undergoing vitrification, especially when mixed with each other.

INDEX

TO THE EXPERIMENTS DESCRIBED IN THIS WORK.

Conversation 1.

1. Copper may be dissolved in *sulphuric acid* by the aid of nitric acid, and crystals of *sulphate of copper* obtained from the solution. See p. 19.

2. If an acid be dropped into a *solution of soap*, the soap will be decomposed. See p. 20.

3. If iron be put into a solution of *sulphate of copper*, the iron will be dissolved, and the copper precipitated. See p. 20.

4. If iron be dissolved in sulphuric acid, crystals of *sulphate of iron* (copperas) may be obtained from the solution. See p. 21.

Conversation 2.

5. *The heat and light* from a fire may be separated from each other by the intervention of a pane of glass. See p. 24.

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7. *Heat is conducted* with different degrees of celerity by the different metals. See p. 33.

8. *Water* may be *boiled* in the upper part of a vessel, whilst ice remains at the bottom of it. See p. 35.

9. *Ether burnt* upon the surface of water will not communicate heat to that fluid. See p. 36.

10. *Heat* may be *reflected* from polished metallic surfaces, and concentrated in the focus of a mirror. See p. 38.

11. The *radiation of heat* is greatly influenced by the kind of surface possessed by the heated body. See p. 40.

12. A *blackened metallic vessel* will be rapidly heated before a fire, whilst one which is polished will remain cold for a considerable length of time. See p. 42.

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13. Bodies are *expanded by being heated.* A metallic ball which when cold exactly fits a brass ring, will not pass through it when warmed. See p. 44.

14. That the *different metals expand differently* may be shown by the pyrometer. See p. 45.

15. Different *fluids expand differently* by the same degrees of heat. See p. 46.

16. That air expands may be shown by the air thermometer. See p. 48.

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17. Water may be boiled in a Florence flask over a lamp, and the process readily examined. See p. 55.

18. Water contained in a flask, and closely corked whilst boiling, may afterwards be made to *boil violently by the application of ice*, or of cold water. See p. 57.

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23. The quantity of heat which will raise the temperature of a pound of mercury 28°, will elevate a pound of water but 1°. See p. 69.

24. The *rarefaction of air produces cold.* This may be exhibited by placing a thermometer under a receiver on the air pump, and then exhausting the air; its condensation produces heat. See p. 70.

25. A thermometer placed in a vessel of ice or snow, the temperature of which is below the freezing point, will rise to 32° if the vessel be exposed to heat; but as soon as the ice begins to melt, the thermometer will remain stationary. See p. 71.

26. If a pound of water heated to 172° be poured upon a pound of ice at 32° the whole mixture will be of the temperature of 32°.

27. The heat which converts boiling water into steam, does not, in the slightest degree, elevate its temperature. See p. 73.

28. The steam produced contains a very large quantity of heat, which, although latent in the steam, may be rendered sensible. See p. 73.

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Conversation 7.

30. Two fluids, one a saturated solution of *muriate of lime*, the other a similar solution of *sulphate of soda*, on being mixed together, *become solid*, and heat is disengaged. See p. 76.

31. A solution of Glauber's salt saturated and corked up whilst at a boiling heat, will remain fluid when cold, until the stopper is removed, when it will instantaneously *crystallize, and give out heat*. See p. 76.

32. Water may be converted into ice by evaporation from itself under the receiver of an air pump. See p. 79.

33. In the *palm, or boiling glass*, water, or alcohol, may be made to boil by the heat of the hand. See p. 79.

34. Water may be frozen, by evaporation from itself, in the *cryophorus* invented by Dr Wollaston. See p. 80.

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36. A *peculiar taste*, and a *flash of light*, may be produced by the contact of two metals, placed in the mouth. See p. 96.

37. *Wires* may be *made to revolve* by the combined action of electricity and magnetism. See p. 105.

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41. *Iron wire burns* very splendidly in oxygen gas, and will be increased in weight by the combustion. See p. 114.

42. *Sulphur when burnt in oxygen* assumes the gaseous form, and is converted into an acid. See p. 116.

43. A *blue vegetable infusion* will become red if a minute portion of an acid is added to it. See p. 118.

44. A piece of *potassium dropped into water*, will immediately take fire, and burn with great rapidity. See p. 119.

45. A *blue vegetable infusion will be rendered green* by the addition of an alkali.

Conversation 12.

46. By passing the vapour of water over heated iron, the iron is oxidized, and *hydrogen gas* (inflammable air) produced. See p. 123.

47. *Water* may be *decomposed* by the voltaic trough. See p. 124.

48. By an apparatus properly arranged, the *two gases* produced by its decomposition may be *separately collected.* See p. 125.

49. Water may be decomposed, and *hydrogen gas obtained, by the agency of iron* and sulphuric acid. See p. 126.

50. *Hydrogen gas,* issuing from a tube, will *burn with flame.* See p. 128.

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53. A *candle* may be repeatedly *extinguished and relighted* by means of a phial filled with hydrogen gas. See p. 129.

54. If *hydrogen is mixed with atmospheric air,* it will explode when ignited. See p. 130.

55. If hydrogen is burnt under a cold receiver, the *water formed by the combustion* will be condensed within it. See p. 131.

56. *Musical sounds* may be produced by surrounding a burning jet of hydrogen by a tube. See p. 132.

57. *Soap bubbles filled with hydrogen gas* ascend rapidly in the atmosphere. See p. 133.

58. If *filled with a mixture of oxygen and hydrogen,* and a taper be applied to them, they will *explode* with a loud report. See p. 134.

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59. *Sulphur* may be *sublimed,* and converted into flowers of sulphur, by the agency of heat. See p. 136.

60. *Sulphurous acid* is produced by the combustion of sulphur in atmospheric air. See p. 137.

61. A *red rose* may be *bleached* by the vapour of burning sulphur. See p. 139.

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62. *Phosphorus burns* with great splendor in oxygen gas. See p. 143.

63. *Words* written, or subjects *drawn with phosphorus,* will *appear luminous* in the dark. See p. 144.

64. By dropping *phosphuret of lime* into water, *phosphuretted hydrogen* will be produced, which will take fire spontaneously. See p. 146.

65. The same gas may be procured by the action of caustic potash and

phosphorus upon water; and curious *rings of vapour* will be formed by the combustion of the gas. See p. 147.

66. A solution of *phosphorus in olive oil* may be made by carefully rubbing the former with a little of the latter, in a mortar, and then adding more oil. This fluid, if kept in a bottle partially filled with it and closely stopped, will exhibit a luminous appearance whenever the cork is withdrawn. See p. 147.

67. A *fountain of fire* may be produced by mixing some phosphorus with the materials for producing hydrogen gas. See p. 148.

68. *Phosphorus burnt* in a given portion of atmospheric air, will deprive it of its oxygen, and enable us to discover how much it contained. See p. 149.

69. The same fact may be ascertained by the agency of hydrogen gas. See p. 149.

Conversation 15.

70. Fixed air (carbonic acid) is produced by the *burning of charcoal in oxygen gas.* See p. 155.

71. *Water* may be *impregnated* with *carbonic acid* by means of Nooth's apparatus. See p. 157.

72. Carbonic acid is much heavier than atmospheric air, and may be collected in an open vessel by very simple means. See p. 157.

73. Carbonic acid may be *poured from one vessel into another,* like a liquid. See p. 158.

74. This gas may be agitated in an open vessel, like water, and the waves produced distinctly exhibited. See p. 158.

75. *Carburetted hydrogen,* an inflammable gas, may be collected from the mud of ponds, or other waters nearly stagnant. See p. 161.

76. *Heavy carburetted hydrogen* which burns brilliantly, and a large quantity of charcoal, may be obtained from alcohol. See p. 162.

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78. *Ammonia* may be disengaged from sal ammoniac, and collected in the gaseous form in an open vessel. See p. 169.

79. On mixing *two gases,* carbonic acid and ammonia, they will combine and *form a solid* substance, carbonate of ammonia. See p. 171.

Conversation 17.

80. The *breath contains carbonic acid,* and will precipitate the lime from lime-water. See p. 174.

81. Carbonic acid will precipitate lime from water, and redissolve the precipitate. See p. 174.

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82. The *reduction of a metal* may be exhibited by heating red lead, mixed with pulverized charcoal, in a tobacco pipe. See p. 184.

83. The same may be shown by *burning a common wafer.* See p. 184.

84. An *alloy formed* of bismuth, tin, and lead, may be fused upon paper, over a candle, without scorching the paper. See p. 187.

85. By the *oxy-hydrogen blowpipe,* the metals, in general, may be burnt and volatilized. See p. 190.

86. A mixture of *filings of copper,* or filings of iron, *and sulphur,* heated in a flask over a lamp, will combine, and light and heat will be emitted, although no oxygen gas is present. See p. 191.

Conversation 19.

87. Neither nitric nor muriatic acid will *dissolve gold*, but when the two are poured together, its solution is immediately effected. See p. 194.

88. If a *stream of hydrogen gas* be made to blow upon *spongy platinum*, the metal will become ignited, this will inflame the gas, which in its turn will light a taper. See p. 196.

89. Writing, or drawing, executed with a solution of *nitrate of silver*, upon linen, prepared by an alkaline solution, will produce indelible lines. This is the *permanent marking ink*. See p. 197.

Conversation 20.

90. By means of the voltaic battery the *alkali and acid* contained in a neutral salt may be *separated from each other*. See p. 205.

91. By the agency of electricity an *acid may be made to pass through an alkali*, without uniting with it. See p. 205.

92. Sal ammoniac and quicklime are *inodorous*, but when rubbed together in a mortar, a *powerful odour*, that of ammonia, will be produced. See p. 206.

93. If four parts of sulphuric acid be mixed with one part of water, both cold, their combination will produce a heat of upwards of 300°. See p. 207.

Conversation 21.

94. If strong *nitric acid* be poured upon pulverized, fresh burnt, charcoal, a *vivid inflammation* will be produced. See p. 219.

95. *Nitric acid* poured upon warm *spirits of turpentine*, will cause it to *burst into a flame*. See p. 219.

96. If *colourless nitric acid* be exposed to the action of light, this agent will produce decomposition, and the acid will *become coloured*. See p. 219.

Conversation 22.

97. If *nitrous gas*, which is colourless, be suffered to escape into the atmosphere, it will assume a *deep orange red* colour, and nitrous acid vapour will be produced. See p. 222.

98. If pulverized charcoal, or sulphur, be mixed with nitre, and projected, in small portions, into a red-hot crucible, a vivid combustion will take place, affording an example of *deflagration*. See p. 228.

99. A mixture of nitre, salt of tartar, and sulphur, forms *fulminating powder*. A few grains of it heated over the fire explode with a very loud report. See p. 229.

100. A few grains of pulverized *nitrate of copper*, wrapped dexterously in tin foil, after being moistened, will cause the foil to *ignite and emit sparks*. See p. 230.

Conversation 23.

101. If *prussiate of potassa*, which is colourless, be dropped into a solution of sulphate of iron, an intense blue colour will be produced, in consequence of the formation of *Prussian blue*. See p. 232.

102. *Boracic acid* dissolved in alcohol, will cause its flame to assume a beautiful *green colour*. See p. 233.

103. The vapour of *fluoric acid* may be used for *etching upon glass*, by a very easy process. See p. 234.

104. *Fluo-silicic acid gas*, in being absorbed by water, will deposite upon its surface a perfect coat, or pane, of silex. See p. 234.

105. *Various metals* in thin leaves, or fine filings, will *inflame* and *burn* spontaneously in chlorine; so also will phosphorus. See p. 238.

106. A *red rose, pieces of printed calico*, and various other articles, *lose their colour* by immersion in chlorine. See p. 238.

107. If *hydrogen* and *chlorine* be mixed together, and inflamed by the electric spark, an *explosion* will be produced, and muriatic acid will be formed. See p. 240.

108. The direct action of the *solar ray* will produce an *explosion* in a mixture of chlorine and hydrogen. See p. 240.

Conversation 24.

109. If a receiver filled with chlorine be allowed to stand over a solution of muriate of ammonia, *chloride of nitrogen* will be formed; a compound which *explodes with great violence.* See p. 243.

110. A few grains of *loaf sugar*, mixed with half the quantity of *chlorate of potassa*, will *inflame* if touched by sulphuric acid. See p. 244.

111. *Matches* first dipped in sulphur, and afterwards in a mixture of chlorate of potassa, loaf sugar, and sulphur, with a little gum water, *will inflame* if dipped into a phial containing sulphuric acid. Asbestos is put into the phial, as cotton is often used in inkstands. See p. 245.

112. If *phosphorus*, cut into small pieces, be put into a glass with some chlorate of potassa, and the glass be filled with water, on pouring sulphuric acid so as to run down the inside of the glass, and come in contact with the salt, the phosphorus will be *inflamed under water.* See p. 245.

113. If *chlorate of potassa and sulphur* be rubbed together in a mortar, a series of *explosions, like the reports of pistols*, will be produced. See p. 245.

114. If *sulphur*, or the *filings of a metal*, be mixed with the chlorate, a blow will cause the mixture to *explode with a loud noise.* See p. 245.

115. If *muriatic acid* and *ammonia*, both in the gaseous state, be brought into contact with each other, they will combine and *form a solid salt*, the muriate of ammonia. See p. 248.

116. If a *leaf of gold* be put into nitric acid, and another into muriatic acid, they will remain undissolved, but upon pouring the two together *solution will be immediately effected.* See p. 250.

117. If a few grains of *iodine* are heated in a closed glass retort, or receiver, a beautiful *violet coloured gas* will be produced. See p. 252.

Conversations 25, 28, and 30.

118. If equal parts of crystallized sulphate of soda and nitrate of ammonia are rubbed together in a mortar, the *two solid salts* will be *converted into a fluid.* See p. 256.

119. If sulphate of copper and nitrate of potassa be dissolved together in hot water, the two salts will *crystallize separately* on allowing the solution to become cold. See p. 257.

120. If a solution of gall nuts, and a solution of sulphate of iron, both nearly colourless, be mixed together, they will become intensely blue, approaching to black. This is an example of the *formation of ink.* See p. 285.

121. If a coil of platina wire be heated, and then held over alcohol or ether, at a little distance from the surface of the liquid, the wire will become, and continue, of a glowing red colour, occasioned by the combustion of the vapour. The aphlogistic lamp, p. 297, shows this effect in a very pleasing manner.

122. If a solution of gelatine (common glue) be mixed with a solution of gall nuts, or of oak bark, a copious precipitation will take place. This is an example of the *formation of leather.* See p. 302.

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